https://doi.org/10.5194/essd-2023-99
Preprint. Discussion started: 18 April 2023

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IWIN: The Isfjorden Weather Information Network

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Abstract. In an effort led by the University Centre in Svalbard (UNIS), with support from the Norwegian Meteorological Institute (MET Norway), the Isfjorden Weather Information Network (IWIN) is under development in the Isfjorden region, central Svalbard. The network substantially expands upon the relatively sparse existing operational network of weather stations and consists of compact and cost-efficient all-in-one weather stations permanently installed on lighthouses around Isfjorden and onboard small tourist cruise ships trafficking the fjord from the spring to the autumn. All data from the network are freely available online in near real-time via MET Norway's data portals (https://doi.org/10.21343/ebrw-w846). The IWIN data are highly valuable for scientific purposes such as atmospheric boundary layer research, validation and development of numerical weather prediction models and assimilation in these, as well as planning and safe conduction of outdoor activities in the region.

1 Introduction

In this study, we present the Isfjorden Weather Information Network (IWIN), which is a new network of automatic weather stations located in the Isfjorden area, central Svalbard. The network is developed by the University Centre in Svalbard (UNIS) with support from the Norwegian Meteorological Institute (MET Norway).

IWIN consists of compact and relatively cost-efficient all-in-one weather stations measuring near-surface temperature, humidity, wind speed, wind direction and pressure. The stations are robust with no movable parts and they are thereby well-suited for the harsh Arctic climate in Svalbard. The stations are mounted at both fixed points (lighthouses) situated along the shoreline of Isfjorden and on small tourist ships that traffic the fjord from spring to autumn. Hence, the network uses existing infrastructure as instrument platforms and its (added) environmental footprint is therefore minimal. IWIN is under continuous development and as of spring 2023 it consists of 7 weather stations, 4 of which are mounted on lighthouses and 3 of which are mounted on ships (in the following referred to as mobile stations). The data from IWIN are integrated in MET Norway's data infrastructure, and made publicly available in near real-time.

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The usefulness of the IWIN observations is multifold. From a research perspective, IWIN provides valuable in-situ, near-surface weather observations from the Arctic, where such observations are otherwise very sparse. The network supports our need to better document and understand the ongoing strong climate warming in Svalbard (Isaksen et al., 2022), which is well beyond the pan-Arctic warming rate of nearly 4 times the global average (Rantanen et al., 2022). Embedded in the Svalbard climate change are effects such as sea ice retreat (Muckenhuber et al., 2016; Dahlke et al., 2020), extreme precipitation events (Müller et al., 2022) and rain-on-snow events (Peeters et al., 2019; Wickström et al., 2020). Future climate projections indicate further warming and more of these climate change related effects in the decades to come (Hanssen-Bauer et al., 2019, e.g.). The complex topography of Svalbard exacerbates the need for more observations from the archipelago, as the weather typically varies substantially in space due among others to flow phenomena such as gap winds (Jackson and Steyn, 1994), channelling effects (Skeie and Gronas, 2000, e.g.) and katabatic winds (Esau and Repina, 2012). With its rugged coast line, surrounded by steep mountain ranges and deep valleys, the Isfjorden area is no exception. The atmospheric component (and its related forcing) of the fjord system furthermore acts as a boundary condition for geological, physical and biological interactions in the region (Cottier et al., 2007; Walczowski and Piechura, 2011; Nilsen et al., 2016; Descamps et al., 2017; Skogseth et al., 2020; Schuler et al., 2020).

Numerical models are integral parts of several of the above-cited studies of weather and climate processes in Svalbard. However, such models typically struggle to accurately represent weather and climate processes in the Arctic (Jung et al., 2016). Recent progress has yielded promising results (Bromwich et al., 2016), and MET Norway's Arome Arctic model (covering Svalbard and northern Fennoscandia, Müller et al. (2017)) has been shown to perform favourably compared to e.g. the global forecasting model of the European Centre of Medium-Range Weather Forecasting (ECMWF, Køltzow et al. (2019)). Further progress in model development, both related to validation and assimilation purposes, relies heavily on more observations such as those provided by IWIN. High-resolution observations are especially useful as we progress towards hectometric scale model simulations, which are currently in testing for Svalbard (Valkonen et al., 2020).

IWIN data are also useful in a societal context, especially because the Isfjorden region is the most populated area in Svalbard. Here, we find the settlements of Longyearbyen, Barentsburg and Pyramiden, and human activity is widespread in the form of, among others, fishery, tourism and research activities. In particular the two latter peak during summertime. Furthermore, emergency situations may occur at any time of the year in the harsh arctic environment of Svalbard, frequently sparking search and rescue missions. Online, near real-time weather observations, like those provided by IWIN, are key to keeping the planning and conduction of such activity as safe as possible.

The primary goal of this paper is to provide documentation on the instrumental setup of IWIN. This includes information on the instrumentation in use, introductions to the observation locations as well as a description of the data handling process (Section 2). In Section 4, we give an overview of the data set as available at the time of publication of this paper and provide information on how to access it. By presenting several examples of weather phenomena observed through IWIN in Section 5, we highlight the novel capabilities of the network and indicate potential usage for future work. In the end, we summarize the current status of IWIN in Section 6 and give an outlook on the further development of the network in Section 7.

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2 Weather Station Network

Comprising a combination of stationary and mobile automatic weather stations, IWIN provides near-surface observations of temperature (T), relative humidity (RH), pressure (p), wind speed (WS) and wind direction (WD) from a large portion of Isfjorden. Thus, IWIN complements the long-term reference surface weather stations operated by MET Norway located around the fjord, at Isfjord Radio (IR), Svalbard Airport (LYR), Nedre Sassendalen (NS) and Pyramiden (PYR). As some of the land-based IWIN station locations are inaccessible for large parts of the year, using rugged all-in-one weather stations with no moving parts ensures low risk of failure and long maintenance intervals. By making use of already existing infrastructure, observations from remote areas are obtained at low cost, while at the same time the local, additional environmental impact of these observations can be considered negligible. All observations are automatically transferred from the stations to UNIS in regular intervals via the 4G cellular network. In the following, the individual station locations are introduced in more detail.

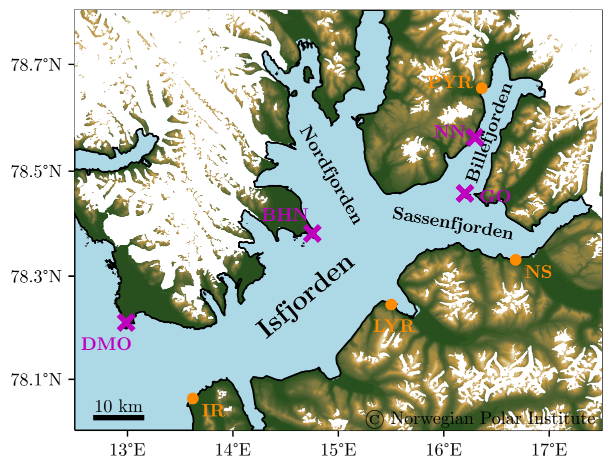

Figure 1. Overview map of the Isfjorden area. Local fjord names are given in black, locations of MET Norway weather stations are marked with orange dots and the IWIN lighthouse stations are marked with magenta crosses. See main text and Table 1 for full station names. This and all following map figures are produced using map data from the Norwegian Polar Institute (https://geodata.npolar.no).

2.1 Lighthouse Stations

Presently, IWIN comprises 4 stationary stations around Isfjorden (for the exact geographical locations see Table 1 and Figure 1). The stations are installed on top of small coastal lighthouses (see Figure 2), approximately 3.6 m above ground level. The instruments used are Campbell Scientific MetSens500 sensors, configured to measure T, RH, p, WS and WD at a raw sampling frequency of 5 seconds. The raw data gets averaged over 1 min and 10 min intervals, filtered for nonphysical outliers and stored in daily netCDF files.

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Table 1. Overview of lighthouse stations

Location (abbreviation)	Latitude [°N]	Longitude [°E]	Measurement altitude (above sea level) [m]	Installation date
Bohemanneset (BHN)	78.38166	14.75300	12	19 August 2021
Narveneset (NN)	78.56343	16.29687	7	17 June 2022
Daudmannsodden (DMO)	78.21056	12.98685	39	08 July 2022
Gåsøyane (GO)	78.45792	16.20082	19	03 September 2022

Figure 2. Sensor installed on top of the Gåsøyane lighthouse.

The first lighthouse station was installed at Bohemanneset (BHN) in August 2021. This lighthouse is located at 8 m above sea level on the tip of the flat headland Bohemanflya. The location sticks out approximately 10 km into central Isfjorden in the south-easterly direction (see Figure 1), in relation to the nearest major mountains in the northwest. The wind rose from this station (Figure 3) shows the prevailing wind directions to be aligned with three major (side-)fjord axes. The main sectors NW–N and NE–E resemble outflow from Nordfjorden and Sassenfjorden, respectively. The secondary peak for SW directions matches inflow into Isfjorden along the main fjord axis. The highest wind speeds almost exclusively occur with flow out of Sassenfjorden (see the example case presented in Section 5.3 for more details and the importance of channeling effects on the local near-surface winds there). Until May 2022, temperature measurements from BHN were stored as samples at the respective time step. This was changed to averages of the raw data over the respective interval (1 min and 10 min, see above) in order to unify the total IWIN dataset.

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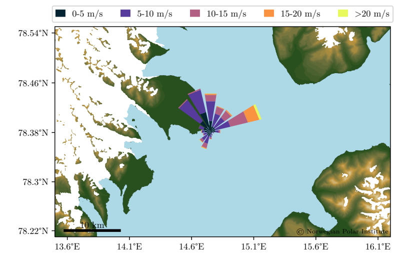

Figure 3. Wind climatology at Bohemanneset, including all data available at the time of publication (19 August 2021 – 20 March 2023).

After the BHN station had operated flawlessly throughout winter 2021/2022, three more lighthouse stations were installed during the summer of 2022. The first of these (installed in mid-June 2022) is located at the western shoreline in central Billefjorden, on a small headland called Narveneset (NN, approximately 3 m above sea level, see Figure 1). Billefjorden is the innermost sidearm of Isfjorden and is surrounded by steep topography. As could be expected, the wind observations from NN show a very dominant alignment with the fjord axis (NE–SW, see Figure 4).

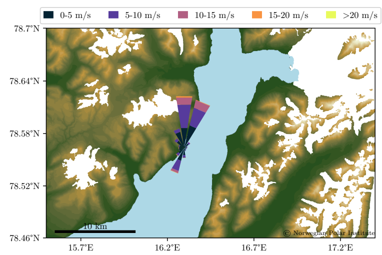

Figure 4. Wind climatology at Narveneset, including all data available at the time of publication (17 June 2022 – 20 March 2023).

The station at Daudmannsodden (DMO, installed in the beginning of July 2022) is situated at the northern shore right outside the mouth of Isfjorden (see Figure 1). The location is distanced from the nearest coastal mountain ranges by the approximately 8 km wide Daudmannsøyra headland. The lighthouse itself is located on a small hill rising approximately 20 m above the surrounding flatland, resulting in a total station height of 35 m above sea level. The observations from this station exhibit stronger maritime characteristics than the other stations (smaller annual temperature range and on average higher specific humidity, not shown). This is most likely due to the influence of the large open water body in Fram Strait and the warm water masses transported northwards there by the West Spitsbergen Current. Winds from westerly sectors are fairly equally distributed over all respective directions, presumably due to no guiding topography upstream of the station for those sectors (see wind rose in Figure 5). The main (easterly) peak in the wind rose is still strongly related to outflow through the mouth of Isfjorden and winds aligned with the valleys in the nearby coastal mountain ranges.

The hitherto last IWIN lighthouse station was installed at Gåsøyane (GO) in the beginning of September 2022. Gåsøyane is a group of small islands at the intersection of Billefjorden and inner Sassenfjorden (see Figure 1). The lighthouse with the

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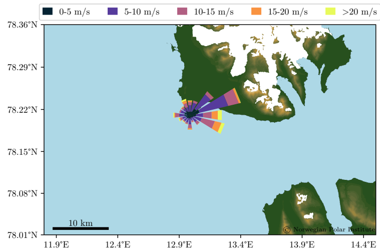

Figure 5. Wind climatology at Daudmannsodden, including all data available at the time of publication (08 July 2022 – 20 March 2023).

station on top is located on the biggest island on a small cliff approximately 15 m above sea level. The axes of both Billefjorden and inner Sassenfjorden (NE–SW and SE–NW) are strongly imprinted in the observed wind direction distribution (see wind rose in Figure 6). Additionally, a secondary peak resembles inflow into outer Sassenfjorden.

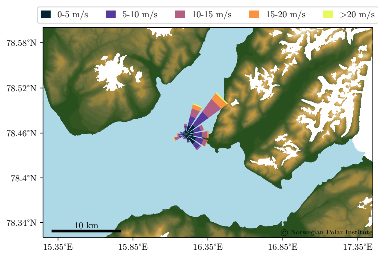

Figure 6. Wind climatology at Gåsøyane, including all data available at the time of publication (02 September 2022 – 20 March 2023).

In combination with MET Norway's reference surface weather stations in the region, the IWIN lighthouse stations provide a good overview of the weather conditions in different parts of the Isfjorden system at all times. Furthermore, different subsets of the network can for example be used to investigate local gradients within the fjord system, e.g. along the main fjord axis (DMO/IR – BHN/LYR – GO – NN – PYR) or across the fjord (DMO – IR, BHN – LYR, NN – GO – NS).

2.2 Mobile Stations

In addition to the lighthouse stations operating year-round, a set of mobile weather stations complete the IWIN network from spring to autumn each year. During the first season of operation in 2021, two stations were installed on the tourist cruise ships MS Bard (a modern catamaran with hybrid-electric propulsion system, 24 m long) and MS Polargirl (approximately 35 m long passenger vessel with a classic streamlined design). In 2022, a third station was added on MS Billefjord (similar dimensions and design as MS Polargirl). The instruments are installed at the top of the ships' masts at 17 – 18 m above sea level (see Figure 7), to minimize disturbance of the measurements caused by flow distortion from the ships' own structures. The sensors used are Gill MaxiMet GMX500, configured to sample at a raw frequency of 1 Hz. In addition to the standard meteorological variables T, RH, p, WS and WD, they provide heading and GPS position measurements. The raw data gets averaged over three different

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intervals: 1 min, 10 min (same as the lighthouse station measurements) and 20 s (for higher spatial resolution along the ship tracks). Subsequently, the data are filtered for nonphysical outliers. Based on the raw wind direction measurements relative to the ship, an additional variable is introduced to mark data points potentially affected by the ship's exhaust plume (see Table 2 for the respective wind direction sectors). Note that MS Bard does not have this problem as its exhaust funnel is located down at sea level. Prior to May 2022, T, RH and p were sampled as instantaneous values at the end of each averaging interval. This was changed to the above-described averaging procedure in order to unify the IWIN dataset.

Figure 7. Sensor installed on top of MS Bard, marked with a red circle.

Table 2. Overview of mobile stations and respective exhaust plume sectors.

Ship	exhaust plume sector [1)]
MS Bard	no filtering needed
MS Polargirl	215 – 235 °
MS Billefjord	170 – 190 °

[1)] relative to the ship, 0 ° resembles head wind

3 Measurement Uncertainties

Just like any other measurement, the IWIN observations are subject to uncertainties. The primary source of uncertainty for both lighthouse and mobile stations are the sensors themselves, quantified by the manufacturers' resolution and accuracy

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specifications (see Table 3). Furthermore, the harsh Arctic environment of Svalbard presents challenges to the equipment. The instrumentation used in IWIN has been chosen accordingly. With no movable parts, the sensors are robust and operate well during all sorts of environmental conditions. Finally, regular maintenance intervals ensure consistent high data quality.

Table 3. Measurement resolutions and accuracies for the sensors used in IWIN as stated by the manufacturers (lighthouse stations: https://s.campbellsci.com/documents/us/product-brochures/b_metsens500.pdf, mobile stations: https://gillinstruments.com/wp-content/uploads/2022/08/1957-008-Maximet-gmx500-Iss-9.pdf).

	T	RH	p	WS	WD
resolution	0.1 K	1 %	0.1 hPa	0.01 m/s	1 °
accuracy	± 0.3 K at 20 °C	± 2 % at 20 °C	± 0.5 hPa at 25 °C	± 3 % up to 40 m/s	± 3 % up to 40 m/s

Quality assurance of mobile measurements such as made as part of IWIN presents additional challenges. For example, measurements of both WS and WD have to be compensated for the ship's motion. Currently, the raw wind measurements are corrected for the ship's horizontal movement using GPS speed and heading data via basic vector geometry during times when the ship is moving faster than 0.25 m/s (approx. 0.5 knts). The effect of higher-frequency ship motion (e.g. pitching and rolling motions in heavy seas) on the final data set can be assumed to be rather small, as the temporal averaging of the raw data into the final data files acts as a low-pass filter. Furthermore, ships' own superstructures are known to influence the wind field in its close proximity. A recent study at UNIS (Reen, 2022) has investigated the flow distortion around MS Bard using CFD simulations. The results showed that flow distortion has quantitatively little impact on the measurements at the location of the sensor, which is situated at the highest point of the ship.

4 Data Availability

As of the time of publication, all lighthouse stations have been measuring continuously since their respective installation dates (see Table 1 and Figure 8). To ensure year-round operation, the lighthouses themselves are equipped with a Ni-Cd-battery bank and a set of solar panels to charge the batteries outside the polar night. The battery capacity is large enough to bridge the polar night (approximately end of October until end of February) and also provides the power for the weather station. Besides the actual station, the modem used to transmit the measured data is the largest power consumer. In order to limit this additional power consumption by the modem, data transmission from the stations to the processing unit at UNIS is taking place only once every 30 min.

Unlike the lighthouses, the ships serving as platforms for the mobile stations only operate within the time frame March to October. Consequently, measurements from the middle of Isfjorden are only available for this time of the year (see Figure 8). From day to day, the three ships follow different schedules and routes, however, they generally visit the same destinations (mainly Pyramiden, Barentsburg and the glaciers in the north- and eastern parts of Isfjorden). Combining the measurements from all mobile stations results in the track pattern and corresponding spatial data density indicated in Figure 9. It shows that

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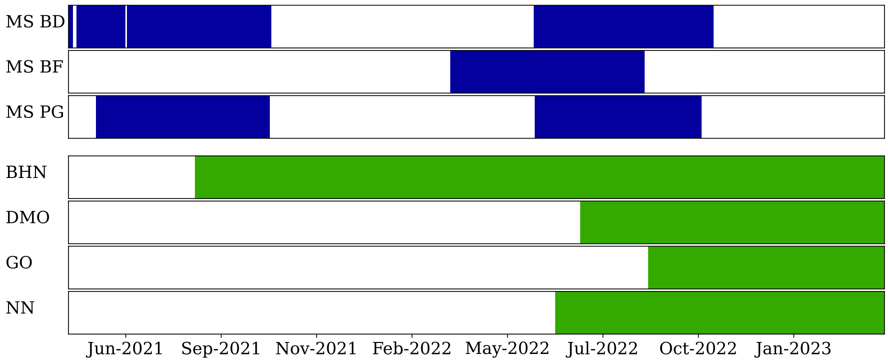

Figure 8. Temporal data availability from the installation of the first station in spring 2021 until the time of publication (20 March 2023). The mobile stations are colored in blue, the lighthouse stations in green.

the tracks cover large parts of Isfjorden from the mouth area in the west to the head of Billefjorden in the east. As power consumption is not a limitation on the ships (the weather stations are powered by the onboard power supply), the modems of the mobile stations are continuously running and the newest data gets transmitted to UNIS for processing every 2 min.

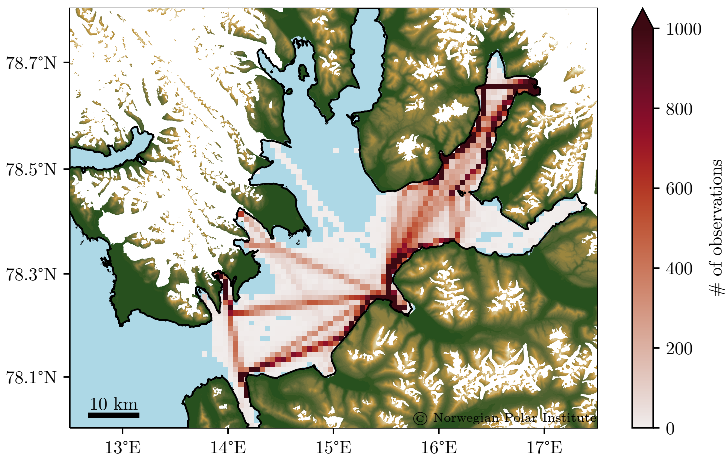

Figure 9. Overview map of the tracks where observations are available from the 3 mobile weather stations from the seasons 2021 and 2022. The spatial density of observations is discretized (counted) in boxes of size approximately 1x1 km and indicated in shades of red, based on a temporal data resolution of 1 min.

150 The published data are stored in files with different temporal resolution (10 min, 1 min, 20 s) using the netCDF4 format. The files are transferred from UNIS every 5 minutes via Secure File Transfer Protocol to a virtual server owned by MET

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Norway. From there, the data become publicly available in near real-time (time lag of approximately 5 – 10 min). They can be openly accessed through the website https://thredds.met.no/thredds/unis-obs/unis-obs.html, which uses Thematic Real-time Environmental Distributed Data Services (THREDDS), an open-source software solution for providing a way to publish and access scientific data in a distributed environment. THREDDS supports a wide range of remote data access, including OPeNDAP (Open-source Project for a Network Data Access Protocol). Additionally, the full data set is registered at MET Norway's Arctic Data Centre (ADC, https://doi.org/10.21343/ebrw-w846, Frank et al. (2023)). The ADC offers additional functionality to access and download the dataset as ASCII-formatted text files as well as direct visualization via a graphical user interface (https://adc.met.no/metsis/search?fulltext=IWIN and subpages).

5 Examples of Observed Weather Phenomena

In the following, we will present four examples of IWIN observations of small-scale weather phenomena. Common for all of them is that they are related to the local terrain around Isfjorden and they show how the local weather conditions experienced in parts of the fjord system may substantially differ from the prevailing synoptic forcing. The presentation of these examples demonstrates the capabilities of IWIN to observe these local weather phenomena and shows potential for future use of the data set. A further, in-depth analysis of the phenomena is beyond the scope of this paper.

5.1 Marine vs. Terrestrial Measurement Footprint

During the period 04 – 06 April 2022, Svalbard was situated under a weak to moderately strong easterly flow field, set up by a high-pressure system to the north and a low pressure system to the south. MET Norway Weather station observations from the Isfjorden region largely conformed to this easterly flow during these dates and their temperature and humidity observations were fairly stable (not shown). However, the observations from the BHN lighthouse station (Figure 3 (a)), draws a different picture. Several large step changes in temperature and specific humidity are seen. For instance, there is a marked drop in both temperature and specific humidity in the first few hours of 04 April by almost 8 K and 0.5g/kg, followed by an equally sharp increase just minutes later. These step changes coincide in time with a change in wind direction from NE to NW and back to NW. A closer look at the satellite picture in Figure 3 (b) reveals that air masses advected from NE originate from over the open water (marine footprint) and air masses advected from NW originate from land (terrestrial footprint) at BHN. It is worth noting that large parts of central Isfjorden typically remain ice-free during most of the year, and the measurement site at BHN is mostly surrounded by open water year-round from three sides (N – W, see Figure 3). For such conditions, the flat headland of the Bohemanflya peninsula results in a terrestrial fetch area for flow from the NW sector at this station. Land-fast sea ice forming along the coastlines of the peninsula during winter and spring occasionally widens this snow- and ice-covered terrestrial sector. It stands to reason that the relatively warm and moist air mass characteristics over the fjord are related to the impact of the heat and moisture release from that surface. In contrast, air masses advected from the terrestrial sector (NW) have been cooled and dried over land. Interestingly, substantial step changes are also seen in the time series of wind speed (Figure 3 (a)), as there are generally lower wind speeds during periods with advection from the terrestrial sector. This indicates that the

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two regimes (onshore and offshore air mass advection) are not only different in their thermodynamical properties, but also in their dynamical drivers.

An investigation of the full time series of observations from BHN (not shown) reveals that contrasts between terrestrial and marine imprints on the near-surface characteristics, such as those described herein, are particularly strong during wintertime.

One can conclude that, located at the tip of the Bohemanflya peninsula stretching into Isfjorden proper, the BHN lighthouse station offers a unique opportunity to analyse contrasts in near-surface characteristics between marine and terrestrial atmospheric boundary layers.

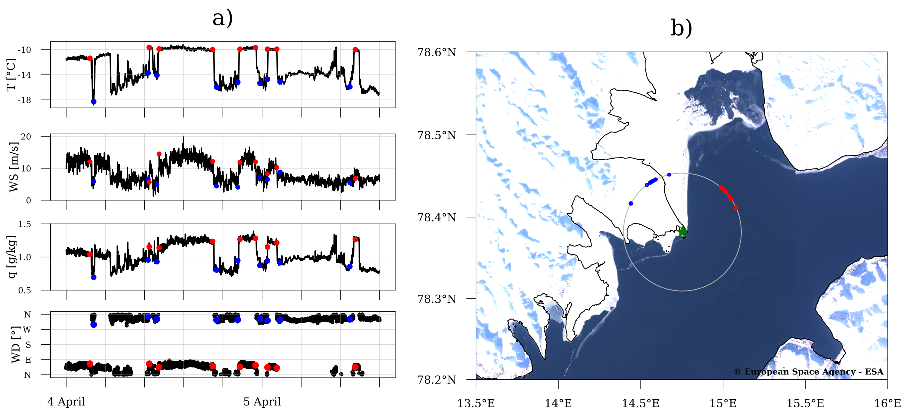

Figure 10. (a) Example time series from the IWIN weather station at BHN from 04 – 06 April 2022 of temperature (T), wind speed (WS), specific humidity (q) and wind direction (WD) during a period when changes in WD induce step-changes in the other three parameters. (b) True color satellite image (composite of two Sentinel-2 overpasses on 05 and 11 April 2022, produced from European Space Agency (ESA) remote sensing data, downloaded from the Copernicus Hub, https://scihub.copernicus.eu/dhus/) centred on the location of BHN (green star). The coast line is marked by a black, solid line. Notable positive and negative step-changes are indicated with respectively red and blue markers in both the time series of T and WD (a) and in the map on a circle centred on BHN (b).

5.2 Glacier Micro-Climate

On the 05 August 2022, the large-scale synoptic forcing was weak over Svalbard. Neither low-pressure systems situated over the Norwegian Sea and the Kara Sea nor a high-pressure ridge in the central Arctic extended far enough towards Svalbard to noticeably impact the weather conditions in the region. The very weak large-scale pressure gradient resulted in low wind speeds over Isfjorden. For the period of the boat tracks from MS Bard and MS Polargirl shown in Figure 11 (06:00 – 17:00 UTC), the average wind speed measured at BHN was 2.3 m/s and came from N–E directions (not shown), indicating predominantly marine influence at this location. Furthermore, prevailing overcast conditions (as seen in satellite pictures, not shown) in combination with the sun not setting (midnight sun) largely suppressed the evolution of a diurnal cycle in the near-surface

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air mass characteristics and temperatures at BHN remained between 8.8 – 9.8 °C throughout the presented time period (not shown).

In the absence of strong synoptic-scale forcing, combined with throughout overcast conditions and polar day, local factors related to the landmasses surrounding Isfjorden can be expected to dominate the near-surface atmospheric conditions experienced in different parts over the fjord. Figure 11 shows the anomaly in observed temperature on MS Bard and MS Polargirl. The anomaly is quantified in terms of subtracting the temperature measured at BHN from the temperature measured on the ships at any given time. Assuming that the BHN temperature represents the 'pristine' and marine air over Isfjorden, the presented anomaly can be said to give an estimate of the influence of the local landmasses on the near-surface atmosphere over Isfjorden at the different locations observed by the mobile stations on the ships.

A marked gradient is evident in the near-surface temperature anomaly field over Isfjorden, when going from the relatively warm southeastern shore and central parts of the fjord to the relatively cold northernwestern shore, especially towards the two bays on that side of the fjord.

Given the NW flow down over the glaciated surface into the aforementioned bays during the time of the observations (Figure 11), it stands to reason that these relatively cold surroundings are dominant sources in the imprint on the local near-surface temperature field. For reference, the temperature anomalies measured along the boat tracks drop by approximately 2 – 3 K towards the glaciers (compared to the central parts of the fjord). This difference is more than double the magnitude of the temporal variations measured by the fixed lighthouse station at BHN during the same time period (about 1 K, see statement above). In addition to the cooling effect of the glaciers, the local water mass distribution in Isfjorden might have additionally strengthened the signal seen in the temperature anomalies, as relatively warm Atlantic Water tends to enter along the southern shoreline of Isfjorden and circulates the fjord anti-clockwise (Skogseth et al., 2020). Additional sea surface temperature observations along the boat tracks would be needed to investigate the relative contribution of the two impacting factors to the observed north-south (atmospheric) near-surface temperature gradient. Furthermore, it remains an open question whether or how local atmospheric circulation phenomena related to the observed glacier-fjord temperature gradient (e.g. land/sea-breeze circulations or drainage flows) impact both the strength of the observed temperature gradient as well as the spatial extent of the cold air footprint.

5.3 Topographic Channeling and Fjord Jet

In contrast to the previous case (05 August 2022, Section 5.2), the weather conditions in the Svalbard region on 20 September 2022 were dominated by a moderate to strong synoptic flow, set up by a low pressure system over the Fram Strait to the west of Svalbard. This flow induced south–easterly winds over the Isfjorden region. For reference, the average wind speed measured at BHN during 06:00 - 17:00 UTC was 15.9 m/s, with a temperature rise from 1 °C to 2.5 °C at this station, induced by large-scale air mass advection.

The observations from the mobile stations installed on MS Bard and MS Polargirl during this day reveal a large spatial variability in the wind field, both in terms of speed and direction (see Figure 12 (b)). The strongest winds are generally found over and downstream of Sassenfjorden. Here, the wind speed reached up to 20 m/s, which is more than twice the average of all wind speeds measured onboard MS Bard and MS Polargirl this day (8 m/s). The wind direction has a clear alignment with

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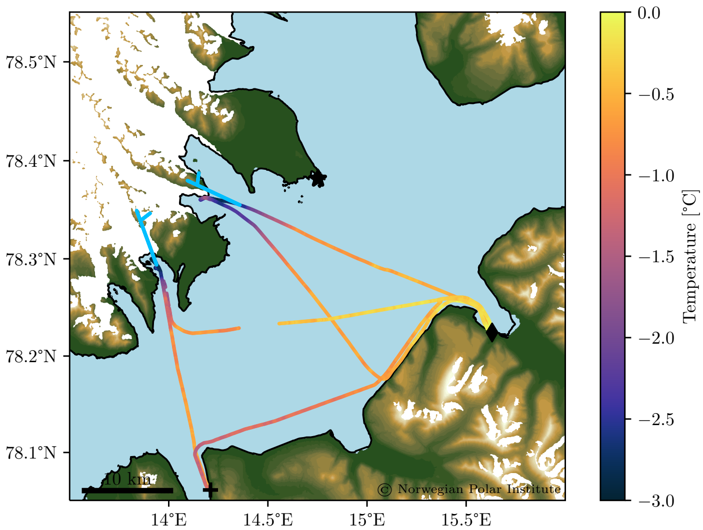

Figure 11. Near-surface air temperature anomalies (colored, solid line) based on observations from the IWIN mobile weather stations on MS Bard and MS Polargirl over Isfjorden using obserations from BHN as reference (ship - BHN observations). The data are obtained during the time 06:00 – 17:00 UTC on 05 August 2022. Data from a stretch of the ship track in the middle of Isfjorden is missing due to a lack of GPS fix, as can be seen as a discontinuity in the ship track and corresponding temperature anomaly. In addition, wind observations from two example points are indicated by the wind barbs. The locations of Longyearbyen, Bohemanneset and Barentsburg are marked with a diamond, a star and a plus symbol, respectively.

the surrounding topography of Sassenfjorden, i.e. from an easterly direction, in contrast to the synoptic flow which was more southerly on this day. The relatively strong wind speeds and clear alignment with surrounding topography are indicative of so-called forced channeling (Whiteman and Doran, 1993). In contrast, very calm conditions with wind speeds of less than 2.5 m/s are found in largely sheltered areas along steep coastlines approximately perpendicular to the large-scale winds, e.g. in inner Billefjorden or along the coastlines north and west of Longyearbyen. Depending on the area considered and its respective topography, these differences occur over distances in the order of 100 m – 1 km. A more detailed view of the measurements along the coastline west of Longyearbyen (Figure 12 (b)) shows that there was also substantial variability present in both the wind direction and in the wind speed in this area. Indeed, some of the observed wind directions are even opposite to the otherwise dominating easterlies over Isfjorden this day. Both such flow reversal and the generally chaotic nature of the wind field in this case are known to occur in wakes during moderate to strong synoptic flow in the lee of sufficiently steep topography (Raupach and Finnigan, 1997).

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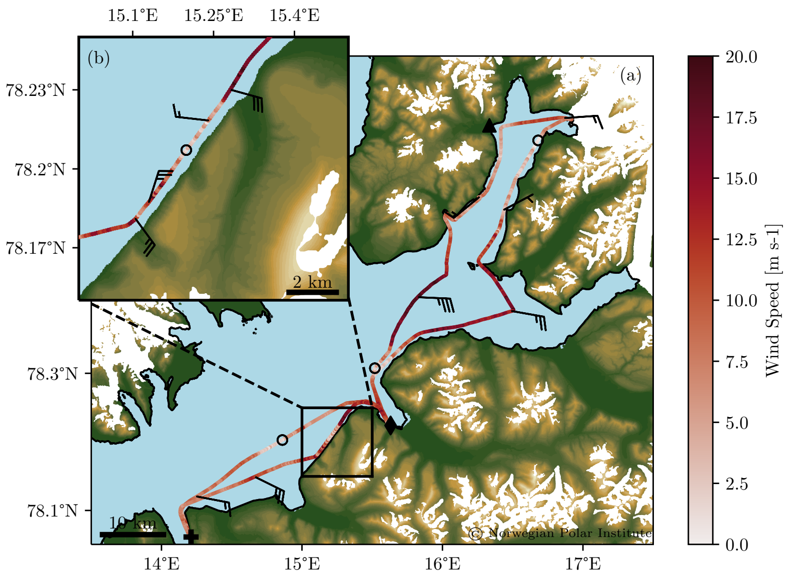

Figure 12. (a) Wind speed (solid line, red shading) and direction (wind barbs) over Isfjorden. (b) A zoom into an area along the coast line west of Longyearbyen with strong temporal and spatial variability in the observed wind. The data presented here are obtained from the IWIN mobile weather stations on MS Bard and MS Polargirl during 06:00 - 17:00 UTC on 20 September 2022. The locations of Longyearbyen, Pyramiden and Barentsburg are marked with a diamond, a triangle and a plus symbol, respectively.

5.4 Drainage Flows

On 20 October 2022, Svalbard was under the influence of a high-pressure ridge extending all over the western central Arctic and Greenland, and a low pressure system centered over Novaya Zemlya. This synoptic setup established a weak but well-defined northerly synoptic flow over Svalbard, advecting cold Arctic air masses over the Isfjorden region. Furthermore, the high-pressure influence led to clear sky conditions (personal observation and also seen in satellite pictures, not shown). Figure 13 shows near-surface wind and temperature data this day from Billefjorden and the adjacent Isfjorden proper, as observed by the mobile station on MS Bard. The lowest temperatures are generally found close to the entrance of valleys, along the shoreline of Billefjorden. For example, the temperature close to Pyramiden is around -2.5 °C. Continuing halfway towards Nordenskiöldbreen glacier (eastwards) the temperature rises by close to a degree, before it drops again down to about -3 °C when arriving by Nordenskiöldbreen. Other areas with relatively cold temperatures include the shoreline outside Pyramiden, Rundodden, Skansbukta, Kapp Ekholm and Narveneset. These observations indicate advection of cold air masses from land and onto the relatively warmer fjord.

A closer look at the ship's wind observations near Pyramiden and Kapp Ekholm reveals that the wind directions at these locations are substantially different from the prevailing, northerly flow on this day. Given the low temperatures at these locations,

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the relatively weak synoptic flow and the wind directions, the air masses are likely driven by a thermal component (drainage flow), set up by the land-sea temperature contrast. The same goes for other locations along the ship track, such as Narveneset, Skansbukta and Rundodden. However, given the orientation of the valleys at the latter locations and the wind direction being aligned with the valley axes, the wind might be (additionally) forced channeling of the synoptic northerly flow.

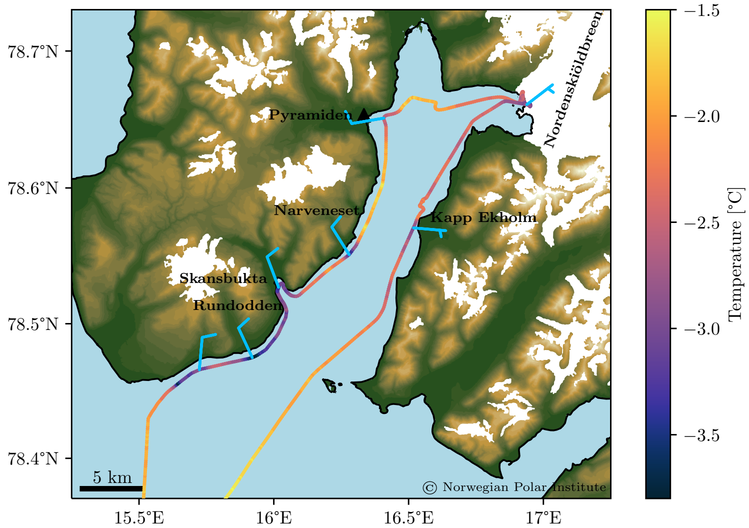

Figure 13. Temperature (solid line, colored shading) and winds (wind barbs) over Isfjorden, as observed by the IWIN mobile weather station on MS Bard during the time 07:00 – 13:00 UTC on 20 October 2022.

6 Summary

IWIN is a new network of weather stations installed on lighthouses and ships in the Isfjorden region. The network is developed by UNIS with support from MET Norway and provides online, freely available and near real-time in-situ meteorological observations from large parts of the Isfjorden fjord system through MET Norway's data portals.

As a high-arctic fjord system, Isfjorden has been subject to strong climate change during the last couple of decades. It has gone from being dominated by Arctic Water during winter to being more dominated by Atlantic Water. Among the consequences is a rapidly diminishing sea ice cover. Atmospheric forcing plays a key role in this regard, which has been documented by among others Cottier et al. (2007); Muckenhuber et al. (2016); Nilsen et al. (2016); Skogseth et al. (2020). So far, these kinds of air-sea-ice studies have mainly relied on model and satellite data and sparsely available in-situ atmospheric observations. IWIN helps fill an observational gap over Isfjorden and it will thereby provide an important basis for future process studies of the importance of intra-fjord, local atmospheric forcing in this climatically important air-sea-ice interaction context

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(Stenlund, 2022). Indeed, the set of cases presented in this paper demonstrates the unprecedented (for the region) capabilities of IWIN to capture local- to meso-scale atmospheric phenomena. These phenomena include sharp contrasts in temperature and humidity between marine and terrestrial-based air masses, as evidenced by IWIN observations along the Isfjorden coast line. The observations also give insight to topographically driven wind phenomena during moderate to strong synoptic flow, such as channelling (fjord jet) and wake effects downstream of and along steep, coastal topography.

Furthermore, observations from IWIN address the need for improving our weather and climate prediction capabilities in the Arctic, which are not as good as at lower latitudes (Køltzow et al., 2021). IWIN does so by providing additional observations from an otherwise data sparse region, both for better process-level understanding (and thereby model and parameterisation development) and also for data assimilation purposes. Indeed, recent efforts applying the IWIN observations in evaluating the AROME Arctic weather model, run operationally by MET Norway for the Svalbard region, have revealed shortcomings (biases) in this system that likely otherwise would not have been detected (Schalamon, 2022). Also, IWIN will support the development and validation of new and ongoing efforts (see e.g. Valkonen et al. (2020)) for building capacity for hectometric-scale numerical weather simulations for the Arctic.

The Arctic is seeing a rather sharp increase in human activity in the form of among others tourism, shipping and research activity. Svalbard, and in particular Isfjorden, is no exception. IWIN helps enhancing the safety of such activity by providing online, freely accessible and near real-time weather data from Isfjorden.

In summary, IWIN supports our needs for a) better understanding and documenting local meteorological processes, relevant for and related to the ongoing rapid climate change in Svalbard, b) enhanced weather prediction capabilities through making unique in-situ observations available for model validation and assimilation purposes and c) enhanced safety for the increasing human activity in the region in the form of among others tourism, research and search and rescue missions through the provision of data that are freely available online in near real-time.

7 Outlook

In concert with the growing demand for in-situ observations in the climate-sensitive region of Svalbard, IWIN is under continuous development. Funding has already been granted for one additional lighthouse station (which will be installed at Kapp Thordsen, 78.45632°N, 15.46768°E, during summer 2023) and one more mobile station. This fourth mobile station will be mounted onboard the UNIS RV Hanna Resvoll. In addition to the standard meteorological variables T, Q, WS, WD and p, it will also provide measurements of photosynthetically active radiation (PAR), which is critical for primary production both on sea and on land. Depending on the scientific needs of the researchers using using the ship, RV Hanna Resvoll will travel into parts of the fjord system not visited by the tourist cruise ships. In that way, the observations from the new station will nicely complement those from the established stations presented in this paper.

Besides the expansion of IWIN by adding more stations, we constantly work towards assuring the highest-possible data quality, especially for the correction of the wind measurements from the mobile stations. One example are efforts currently underway to include satellite-compasses in the mobile station setups. These will give highly accurate estimates of the ships'

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motion and heading at any time and allow for more sophisticated wind measurement corrections, also when the ships are not moving.

Author contributions. Lukas Frank is responsible for the publication of the dataset, including the processing of the raw data into netCDF files and the data transfer to MET Norway. He is also the responsible author of this paper. Marius O. Jonassen is the main responsible for the funding acquisition and contributed with writing to this paper. Teresa Remes is responsible for the organisation of the data at MET Norway's servers. Florina Schalamon and Agnes Stenlund contributed with written text and figures in Sections 2 and 5).

Competing interests. The authors declare that they have no conflict of interest.

Acknowledgements. IWIN has been financially supported by a number of different institutions and projects, including UNIS, MET Norway, Alertness (NFR-280573), N-FORCES (NFR-337229) and the Jan Christensen foundation. These shall hereby all be acknowledged for their support. Stefan Claes provided invaluable help with the installation of especially the lighthouse stations and the coordination with Kystverket, which gladly allowed us to use the lighthouses as platforms and power sources. Special thanks to Henningsen Transport and Guiding, Polarcharter, Hurtigruten and Brim Explorer, including their respective crews onboard the ships, for providing us with mobile measurement platforms. Thanks also to Charlotte Gausa for her help with the installation of the stations and maintenance work.

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