Interactive comment on "Meteorological observations in tall masts for mapping of atmospheric flow in Norwegian fjords" by Birgitte Rugaard Furevik et al.

Anonymous Referee #1
Received and published: 27 July 2020

Overall, this is an excellent paper. The data are easily accessible and well-organized. The dataset is well-described and the justification is clear for collecting such data. Revisions are very minor, and the paper will be an excellent introduction to the dataset.

Response: We appreciate the effort of the reviewer and the positive review. We have revised the manuscript according to the comments of the reviewer, as stated below. Additionally, some more changes have been done to the manuscript, to further improve the written language and the structure of the paper.

Line 242: First sentence here is ambiguous. Does this mean that December wind speeds are 8-9 ms-1, or is that the annual median, with higher speeds in winter?

Response: We agree that the sentence was unclear.

Changes: The sentence is rewritten and now reads: "For this period, the median wind speed at Ona is 6.6 ms^{-1} which varies from 5.1 ms^{-1} in August up to 8.7 ms^{-1} in January (Fig. 9)".

Line 280: It is not clearly explained why this turbulence data is being presented or how to interpret it. Some language could be added here to explain how this information can be useful to a user. Is this particular sample of data being shown because it is particularly interesting, or just an example of the larger set?

Response: We agree with the reviewer that the text was unclear, and as was the motive for showing the figure.

Changes: We have rephased the paragraph (paragraph 7 in section 4) to provide some more details and explanation. The actual data was arbitrarily chosen to show an example of the use of the data, and that is now clearly stated in the text.

Interactive comment on "Meteorological observations in tall masts for mapping of atmospheric flow in Norwegian fjords" by Birgitte Rugaard Furevik et al.

Anonymous Referee #2
Received and published: 8 August 2020

This paper presents a dataset of meteorological observations collected in 11 tall masts in three different fjords systems of Mid-Norway. A large part of the manuscript is devoted to the description of each measurements site, which include useful information about fjords geographic features and operating instruments. The last two sections are dedicated to a (too) brief description of quality control procedures and to a presentation of measured wind, temperature and precipitation data.

As general comment, I think that the authors present an interesting dataset, which can be certainly useful for meteorological and engineering purposes. However, I think that this work has some point of weaknesses that must be addressed before considering it for publication in ESSD. First, the quality presentation of the study is unsatisfactory for the level of a journal such as ESSD: therefore, the first suggestion is to perform a formal revision of the manuscript, improving language and style.

Response: We appreciate the effort of the reviewer and the constructive criticism. We have revised the manuscript according to all received comments and worked on the structure and the language. We believe that the manuscript has improved significantly. Response to each comment from the reviewer and a description of related changes are given below.

From a strictly scientific point of view, the paper must be revised according to the following suggestions:

In my opinion, when presenting the data (Section 4) authors use the word "climate" in an inappropriate way. For example, a period of 18 years (Lines 360) cannot be used to reach any robust conclusions from a strictly climatological perspective. You can speak about climate only when you managed a meteorological time series of at least 30 year. This consideration is obviously and even more so valid for the new dataset presented in this study. For example, at Line 258 you cannot speak about "wind climate", considering only two or three years of data. I suggest to use "wind regime" and to underline that no climatological results or conclusions can be achieved from the available data. You can present your results only from a meteorological perspective. In other words, the wind regime observed in the 11 sites might be affected by the atmospheric variability and anomalies observed in a specific year and/or season, due to the very limited time period taken into account.

Response: It's correct that WMO recommends using the latest 30 years where the last year ends with 0, for calculating climate normal. This is not what we intended to do, or imply we were presenting. We are merely aiming to compare the longest available time series from the closest long-term stations to our data, in order to put the measurements from the campaign in perspective with the regional long-term wind conditions. This highlights the impact of the topography on the local wind conditions, and reveals that the "wind regime" during the period of the observations of the masts is not so different from the climate estimate based on 18 years. We certainly agree that it is wrong to use the word "climate" for a period of only a few years. However, we will insist that 15-20 years of recent observations of wind can represent well the current wind climate at a given site, but such a climate estimate should certainly not be compared to the previously mentioned climate normals typically calculated.

Changes: We have included a new figure (Fig. 12) and changed accordingly the formulation in the first paragraph of section 4. The discussion of climate in other parts of the document have also been changed accordingly, e.g. the word climate is not used when investigating the mean wind conditions based on the short observation series from the sites.

In section 3, the authors describe the data handling and quality. I suggest extending this section, providing more details about data quality control, which is a critical and focal point of any data description paper. My recommendation is to structure the quality control into at least three different step, considering the following tests: 1. Gross error test, which flag data that are above or below acceptable physical limits; 2. The tolerance test, which detects the outliers, i.e. the values that are above or below some specific limits defined according to a probability distribution model; 3. The temporal coherence test, which identifies unrealistic "jumps" between two consecutive observations according to the change that might be expected for a determined variable in a specific time interval. A graphical example for each of the just mentioned basic quality control step should be provided. Moreover, the authors may also consider to apply a fourth quality control step, based on spatial consistency among the available measurements. A useful reference may be following paper, recently published on ESSD:
Capozzi, V., Cotroneo, Y., Castagno, P., De Vivo, C., and Budillon, G.: Rescue and quality control of sub-daily meteorological data collected at Montevergine Observatory (Southern Apennines), 1884–1963, Earth Syst. Sci. Data, 12, 1467–1487, https://doi.org/10.5194/essd-12-1467-2020, 2020.

Other useful references:

Hubbard, K., You, J., and Shulski, M.: Toward a Better Quality Control of Weather Data, Practical Concepts of Quality Control, edited by: Saber, M. and Nezhad, F., ISBN: 978-953-51-0887-0, InTech, https://doi.org/10.5772/51632, 2012.âĂĆ

Steinacker, R., Mayer, D., and Steiner, A.: Data Quality Control Based on Self-Consistency, Mon. Weather Rev., 139, 3974–3991, https://doi.org/10.1175/MWR-D-10-05024.1, 2011.âĂĆ

World Meteorological Organization: Guide to Meteorological Instruments and Methods of Observation, 2008 Edition, WMO-no. 8 (Seventh edition), available at: https://www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/OLD-pages/CIMO_Guide-7th_Edition-2008.html (last access: 1 October 2019), 2008.âĂĆ

Response: The data are made available on thredds at MET for potential users to use as fit. No additional filtering of the dataset can be done by the authors in connection with producing this manuscript, and the public access to the dataset does not depend on the current manuscript. That is, the data is provided as is, and more filtering is beyond the scope of this paper and the budget for making the data available. We believe that this does not render the dataset less valuable for the potential user, and that this description of the dataset should be published in order to facilitate the use of the dataset. However, the end-user must assess his need for further quality control and put effort into the additional filtering routines necessary for his intended use of the dataset.

The filtering already done is described and for more in-depth filtering routines, the reader is directed to a suggestion of papers. The raw observational data for variables other than wind are made available as is, with only a first screening performed. No 10-minute values are made available for these variables. This is now stated in the section. For the 10 Hz observations of wind speed and direction, the filtering is as follows and described in the manuscript: Unphysical values beyond the specifications of the instruments are removed. Noise and spikes, i.e. unphysical jumps in the 10 Hz data, are filtered and removed. Locked values, i.e. repeated and constant values are identified and removed, but such values are somewhat frequent from the instruments. This filtering captures a large part of three of the suggested tests. No spatial testing is done and the authors are not familiar with how well it performs in complex terrain where the flow at one site may often to a large degree be "detached" from the state of the flow at other masts in the region, or even at a nearby mast in the same fjord.

Changes: The whole section has been improved and more details are given in the revised manuscript. Some parts were moved to section 5, i.e. description on access to the data.

About the comparison between reference station and data from masts, I suggest to produce plots based on the same period. I understand that the data availability may be a problem, because it varies from a measurements point to another, but it is necessary to identify a common period allowing performing a real comparison between the wind roses presented in Fig. 11. When discussing this figure, I think that is important to highlight that northeastern winds have a relevant frequency only in Aakvivk A, Gjeveneset A and Rjaaneset A. How do you explain this result? Why in other mast locations the wind regime is so different from the reference one (upper left panel of Fig. 11)?

Response: We agree with the reviewer that it is problematic to compare observations from different periods. We have changed the text as described below, where we highlight that the northeastern flow at Ona is in fact a collection of synoptic scale flow from a wide sector, including flow from the northwest to northeast. That is, orographic forcing of the large scale terrain of western Norway, results in the observed flow at coastal stations typically being along the coast. This implies that northeasterly flow at Ona can be associated with a lot of different directions at the different stations, as now mentioned in the paper. An investigation of the coupling of the wind direction between the reference station and individual stations is beyond the scope of this paper.

Changes: We have included a new figure (Fig 12) in the updated manuscript, but we also choose to keep the original wind roses in order to present the statistics for as long observational periods as possible at each site.

In the new figure there are separate panels for each of the fjords. Wind roses are made for each mast and the Ona reference stations, and only using concurrent data for March 2017 - 2018. The wind roses are overlaid on the terrain, hence highlighting in a qualitative manner the terrain forcing at each site. As only concurrent data is used, wind conditions at all masts can be compared to each other. The text has been changed accordingly and improved considerably (4th paragraph of section 4).

The updates to the text in paragraph 4 of section 4, include an explanation for the different directional distributions at the sites, which are first and foremost due to the orographic forcing.

In the introduction section (Lines 48-49), the authors claim that the measurement campaign presented in their work may have interesting and relevant implications for studies concerning the boundary layer variability in complex terrain. I agree with the authors, but I do not understand why the authors did not further stress this point when presenting the data in section 4. Therefore, I suggest showing some examples of vertical profiles of wind speed, wind direction, temperature and relative humidity obtained from the available measurements. For example, the authors may produce a vertical profile for each of three fjords, considering the measurements that are best suited for this purpose. To highlight the good potential of the dataset, the authors may also present, only for illustrative purposes, a comparison between vertical profiles obtained in different meteorological scenarios.

Response: We agree that the potential of the data can be better visualized. Instead of wind profiles, we have chosen to include an example of time series (Fig. 14) from some of the masts in Sulafjorden, since we find that this is a better illustration of the details that the measurements can represent.

Changes: A new figure (Fig 14) is included and is discussed in an updated and re-phrased paragraph (fifth) in section 4. Note that in connection with the new text, then we have moved the paragraph on precipitation to be the last in the section.

Interactive comment on “Meteorological observations in tall masts for mapping of atmospheric flow in Norwegian fjords” by Birgitte Rugaard Furevik et al.

Anonymous Referee #3

Received and published: 15 August 2020

This manuscript presents details of the meteorological observation system at the Norwegian fjords. As a part of coastal highway project, wind is the focused parameter measured at multiple vertical levels at 11 locations extending over 2-10 years of record. The dataset consists of high frequency and long-term measurements of wind speed and direction as well as other meteorological fields at selected locations. I think that the dataset is of significance to the research and engineering communities, and the manuscript covers basics of a data description paper but I have a few suggestions to improve.

Response: We appreciate the effort of the reviewer and the positive review. We have revised the manuscript according to the comments of the reviewer, and our response and change related to each item is given below.

1. Figure 11: I recommend plotting the wind rose at 11 stations overlaid and pointing to the location on the map to give a perspective of the entire region. Like the example figure (with partial stations)

Response: We certainly agree with the reviewer.

Changes: We have provided a new figure as suggested (figure 12), with separate panels for each of the fjords. Wind roses are made for each mast and the Ona reference stations, and only using concurrent data for March 2018 - 2019. The wind roses are overlaid on the terrain and highlight the terrain forcing at each site. As only concurrent data is used, wind conditions at all masts can be compared to each other. The text has been changed accordingly and improved considerably (fourth paragraph of section 4).

2. Quality control is an important part of data description. I think that Section3 Data handling and Quality should be dedicated to quality control. The current content is mainly on processing and transmission, that seems to fit in Section 5. What is the latency of the dataâĂŤnear real time?

Response: The data are made available on thredds at MET for potential users to use as fit. However, beyond the filtering already done, no additional filtering of the dataset can be done in connection with producing this manuscript. That is the data is provided as is and a more filtering is beyond the scope of this paper and the budget for making the data available. We believe that this does not render the dataset less valuable for the potential user, and that the data is still useful and a description of it

still should be published, in order to facilitate the use of the data. However, this means the user must put an effort into the filtering routines he sees needed for his intended use of the dataset. The latency of the data is on the order of hours to days, as now stated in the manuscript.

Changes: Section 3 has been expanded and improved, with more details on the quality control which has been employed on the 10 Hz data. Some parts of the previous section 3 were moved to section 5.

3. Figure 13: How long does the observation record go back at the reference site? Is it available before 2009? If so, it would be nice to use longer time mean.

Response: ONA II has been operational since 1978 and we have used 18 years of data (2001-2019) with hourly temporal resolution. Before 2001, recordings were less frequent, not automated and done with a different instrument. We have therefore chosen to use the longest homogeneous part of the series in order to not introduce any discrepancies which could be associated with a longer time series.

Changes: We have modified the first paragraph of section 4.

4. Line 246-247: I don't understand this sentence, please clarify.

Response: We agree that the sentence was unclear.

Changes: We have rephrased the sentence to better convey the message, and it now reads: "When compared to the wind speed distribution for the reference period of 18 years (Fig. 9) we see that the wind has been somewhat weaker during the last 3 years than during the reference period."

Interactive comment on “Meteorological observations in tall masts for mapping of atmospheric flow in Norwegian fjords” by Birgitte Rugaard Furevik et al.

Comments by Etienne Cheynet
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Response to these comments were already published, and we have taken them into account when revising the manuscript as indicated below.

The manuscript "Meteorological observations in tall masts for mapping of atmospheric flow in Norwegian fjords" by Furevik et al. deals with a unique data set, freely accessible since 2018, which is particularly valuable for both engineers and scientists working on the E39 Coastal Highway Route (Ferry Free E39). Nevertheless, some of the statements in the manuscript may be unclear, ambiguous or misleading:

• *Line 59, the authors mention that the "dataset provides invaluable data describing the atmospheric forcing, both climatic and short-term, pertaining to the technical design of large structures in complex terrain." Although I understand the enthusiasm of the authors, one should keep in mind that the potential and limits of the dataset have not yet been assessed in details.*

Changes: The sentence is rephrased and some text is added in paragraph 4 of section 1.

It is also unclear to me what the authors mean exactly by "atmospheric forcing, both climatic and short-term" with respect to structural design. A more specific reformulation would be welcome.

Changes: We have changed the word to “forces”.

• Line 34-35. As the authors already know, there has been a similar campaign in the Bjørnafjord since 2015. Although the data in that fjord are not publicly available, it may be useful to the reader to know that the campaigns in the Sulafjord, Halsafjord and Julsundet are not the only ones.

Changes: We have added a sentence in paragraph 2 of section 1 about the other measurement campaigns of NPRA.

• Line 98: If no filtering is applied beforehand, downsampling a time series from 20 Hz to 10 Hz will amplify aliasing not reduce it. In general, downsampling increases aliasing. As far as I know, the downsampling procedure was done without filtering, resulting in undesirable aliasing, visible in Figure 15, at frequencies above 4 Hz.

Changes: No change was made since the temporal resolution is decreased by averaging two samples.

• It may be informative to the reader to know if the high-frequency sonic temperature is freely available or not. I am aware that some 2-Hz sonic temperature records are usable, but this sampling frequency may be too low to study turbulent fluxes. A sampling frequency of 10 Hz or more is desirable for such purposes.

Changes: We have added a sentence at the end of paragraph 2 in section 2.1.

Meteorological observations in tall masts for mapping of atmospheric flow in Norwegian fjords

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Abstract. Since 2014, 11 tall meteorological masts have been erected in coastal areas of mid-Norway in order to provide observational data for a detailed description of the wind ~~climate~~conditions at several potential fjord crossing sites. The planned fjord crossings are part of the Norwegian Public Roads Administration (NPRA) Coastal Highway E39-project. The meteorological masts are 50 - 100 m high and located in complex terrain near the shoreline in Halsafjorden, Julsundet and Storfjorden in the Møre og Romsdal county of Norway. Observations of the three-dimensional wind vector are done at 2-4 levels in each mast, with a temporal frequency of 10 Hz. The dataset is corroborated with observed profiles of temperature at two masts, as well as observations of precipitation, atmospheric pressure, relative humidity and dew point at one site. The first masts were erected in 2014 and the measurement campaign will continue to at least 2024. The current paper describes the observational setup and observations of key atmospheric parameters are presented and put in context with observations and climatological ~~normals~~ data from a nearby reference weather station. The ~~quality-controlled~~ 10-minute and 10 Hz wind data as well as other meteorological parameters are~~is~~ publicly available through Arctic Data Centre (~~https://adc.met.no/datasets/~~ DOI: 10.21343/z9n1-qw63; Furevik et al., 2019).

1 Introduction

In 2014, the Norwegian Public Roads Administration (NPRA) started an evaluation of the environmental conditions, i.e. wind, atmospheric turbulence, waves and currents, pertaining to making the E39 road 'ferry-free' between Kristiansand and Trondheim on the western coast of Norway. If realised, the project will include new crossings of eight of the largest fjords in Norway. The fjords are typically surrounded by steep mountains going up to 500 m. Fjord widths are 2-7.5 km, and water depths 200-1300 m. This requires a detailed understanding of the wind, wave and ocean current climate at the proposed crossings which is achieved partly through a large atmospheric and oceanographic measurement programme.

In mid-Norway new fjord crossings are planned in Vartdalsfjorden, Sulafjorden and Halsafjorden, as well as ~~in~~near Julsundet. The observational campaign started here in 2014, with a considerable increase in measurement effort in October 2016. The observational programme will continue for at least 8 years, but may be extended to 12 years or more. The program includes tall meteorological masts erected and operated by Kjeller Vindteknikk (KVT), equipped with sonic anemometers at several evelations, observing with a temporal resolution of 10 Hz~~, at several elevations~~. The most recent masts are 70-100 m high while the masts erected first have an elevation of ~50 m. A number of wave buoys with meteorological and oceanographic measurements ~~are~~have also been installed. Similar measurement campaigns are carried out by the NPRA in other fjords, such as Bjørnafjorden, but these data are not publicly available. The fjord measurement programme of the NPRA is unique in Norway, both in terms of measurement density, parameters measured and the time frame. To the authors knowledge, there has been no other dedicated measurement campaign, providing simultaneous and detailed measurements of both the ocean and the lower atmospheric boundary layer in the complex coastal terrain of western Norway. Oceanographic and atmospheric measurements have typically been carried out independently and during shorter periods, related to e.g. research programmes or industry projects. Ongoing large observation programmes include the LoVE, Lofoten–Vesterålen Cabled Observatory of the shelf marine ecosystem (Godø et al., 2014), the Integrated Carbon Observation System (ICOS)-

Norway and Ocean Thematic Centre (OTC) which is an international observation programme of greenhouse gasses (Steinhoff et al. 2019), and the Nansen Legacy, a national research programme which includes extensive observations in the northern Barents Sea and Arctic Ocean (Reigstad et al., 2019). The Norwegian Meteorological Institute (MET Norway) operates a national network of meteorological stations (observational data typically freely available) in the region of the E39 campaign. The NPRA and the National Coastal Administration (NCA) operate meteorological stations in connection with infrastructure and road safety/operations, but wind measurements from these stations may be strongly affected by obstacles and local terrain features. The Frøya meteorological mast recorded ocean wind conditions to form the basis for the NORSOK standard (Andersen and Løvseth, 1995, 2006; Standard Norge, 2017).

From a scientific standpoint, the measurement campaign provides an excellent platform to study the multi-scale variability in boundary-layer flow in complex terrain, and the variation of local flow with regard to the synoptic flow aloft, as previously studied by Jonassen et al. (2011) for southern Norway. The current campaign has already provided unique observations of extreme winds and storms in complex terrain, but here the relevant topographic forcing is typically at a smaller scale than has been studied in many large field campaigns in and near the North Atlantic (e.g. the Norwegian IPY-Thorpex (Kristjánsson et al., 2011) and the Greenland Flow Distortion Experiment (Renfrew et al., 2008)). The boundary layer flow in this part of Norway is to a first order governed by a large scale orographic forcing on the mesoscale and synoptic flow, i.e. due to the high mountains of southern and western Norway. The boundary layer flow may decouple from the flow aloft while the local variability near the surface occurs on scales on the order of a few kilometres, as the flow is for example accelerated along steep mountain slopes and narrow fjords, or stagnates in blocked flow in deep valleys, i.e. in terrain typical for the locations of the masts in the campaign. From a more pragmatic and engineering point of view, the ~~observational~~ data collection ~~provides invaluable data set~~ is important for describing the atmospheric forces~~ngi~~, both climatic and short-term, pertaining to the technical design of large structures in complex terrain. The data collection is unique in both the length as well as in the detail of the observed time series at the available sites. The series are long enough so that they can be of use in constructing a description of the climatic conditions at the sites, but they are also detailed enough to describe well single weather events of interest and capture some of the complexity in the flow structure on either side of the planned crossings. The wind and turbulence data has already highlighed that for such large structures as are planned, the spatial variability in the flow must be properly accounted for and described.

The objective of the present paper is to provide documentation of the atmospheric part of the E39 dataset and the data handling process for the mast data. The measurement programme is ongoing and the description given here is valid at the time of publication. The paper is structured as follows. Section 2 describes the setup of the observation system, including mast details, the data quality control and an overview of data availability. Access to the data is open, and handled through a new procedure at MET Norway, which is described in section 3. Section 4 presents observations of selected variables to illustrate available parameters and the data quality, and puts the data in context with the regional climate. A summary is given in section 5.

2 Setup of the observation system

As of December 2019, the observational dataset includes observations from 12~~1~~ tall masts in three main regions of interest in Møre and Romsdal county in western Norway (Fig. 1). All the masts are operational except ~~one~~two: one ~~which~~ has been dismantled, and other was discontinued and extended to twice the original height, becoming the 12th mast. Most masts are expected to be operational for at least 8 years, with more details on their setup given below. The masts are located in a region characterized with a relatively complex orography, e.g. narrow and deep fjords, surrounded by steep and high mountains. The conditions are more challenging in the Storfjorden region (region S in Fig. 1), where the brunt of the campaign is focussed, than in the Julsundet and Halsafjorden regions (J and H in Fig. 1). Further details on the setup and conditions at individual masts is given below. Long-term reference surface weather stations, operated by MET Norway, are found within approx. 20 km of each of the main region of interests. Two of these are located in flat terrain at airports, ~~with upper-air observations~~ while the third is a located on the small island of Ona. The nearest upper air observations are made ~18~~24~~0 km to the northeast from Ona, at Ørlandet airport~~(not shown)~~.

The main focus of the measurement campaign is to collect climatic data on the atmospheric and oceanic conditions at possible fjord crossings, pertaining to the dimensioning and design of ~~very~~ long ~~connections~~structures (suspension bridges and floating bridges have been considered~~ or other~~, as well as submerged tunnels). In this aspect, wind is the most important atmospheric variable. The main parameters of relevance can be split into two sets: a) mean quantities which can be described by e.g. the 10-minute mean wind, i.e. the wind speed and direction distribution, return levels of extreme winds and the vertical wind profile. b) turbulence quantities which must be described using observations with a high temporal frequency, e.g. turbulence intensities, the spectral energy density and coherent variations of the turbulence at two locations separated by short distance. Furthermore, the measurement campaign is corroborated by observations from buoys and LIDARs (not presented here~~yet documented~~), as well long datasets with high-resolution simulations of weather with mesoscale numerical weather prediction and ~~CFD~~computational fluid dynamics (CFD) models (not presented here).

2.1 Masts and instrumentation

A summary of the key parameters for the masts are presented in Table 1, including geographical position, measurement period, base level height and measurement heights. The masts are built and operated by ~~Kjeller Vindteknikk (~~KVT~~)~~ for the NPRA. Observations of wind are made at 2 - 4 levels in each of the masts, while additional~~several other~~ atmospheric variables are observed at three sites. Observations are ongoing at all masts, except at Midsund which was dismantled in March 2019, and at Åkvik which became a new station (Åkvik2) in May 2020 with a lenghened mast. The masts are guyed lattice towers (Storfjorden) and tubular masts (Julsundet and Halsafjorden), except at Kårsteinen, Langeneset and Nautneset which are self-supporting lattice masts. Nautneset has previously been instrumented with an accelerometer to verify that the swinging motion of the self-supporting masts has a negligible impact on the intended use of the wind measurements (Tallhaug, 2017).

The three wind components are recorded using three-axial ultrasonic anemometers (Gill WindMaster Pro) which is logging at 20 Hz. The data is subsequently averaged to a temporal resolution of 10 Hz to ~~minimise~~ reduce aliasing. The anemometers are located on 2 - 6 m long horizontal booms, with the boom directions approximately perpendicular to the prevailing and most relevant wind directions (derived a-priori from mesoscale simulations of wind). The true boom direction, as seen from the mast, is presented in Table 1 (average for all levels). The lowermost sensors at the masts at Julbø, Halsaneset and Midsund are located at ~13 m above ground level and have been found to be too strongly affected by their vicinity to the tree top level. This is to some degree also the case for the lowermost sensor at Åkvik (17 magl). In July 2018 ~~it was known that~~ a software bug was documented, affecting the vertical wind component of instrument produced before October 2015 (Gill Instruments, 2016). This error has been accounted for and only corrected data are made available as a part of the current dataset. 10 Hz temperature measurements were stored from some of the sonic anemometers, but are not part of the available dataset.

The 10-minute mean wind data is produced from the 10 Hz wind recordings and ~~. Since there is no minimum on the amount of 10 Hz samples used in producing the 10-minute averages, the availability of 10 Hz wind data is slightly lower than of the 10-minute mean wind data. The amount of 10 Hz data used to produce 10-minute data can be deduced by inspection of the available 10 Hz data, showing that m~~more than 99.95 % of the 10-minute samples are based on a 50 % or better 10 Hz availability. A 90 % availability of 10 Hz data is found in 99 - 100 % of the 10-minute samples, depending on station. If a 99 ~~-~~% 10 Hz availability is required then the numbers are 96 - 99 % for the 10-minute means.

The total uptime for 10-minute mean wind for all sensors and all masts is 98.9%. ~~Data losses are related to sporadic meteorological disturbances (e.g. precipitation), and times of equipment fault.~~ Instrument failures are fixed at the earliest convenience, with highest priority given to having operational sensors at the top of the masts. An intermittent reduction in 10 Hz data availability is typically associated with errors due to precipitation and other intermittent external or technical disturbances. A malfunctioning instrument or logger will either lead to complete data loss or have sustained periods with a availability far below 100 % for the 10 Hz observations.

The stations Kvitneset_Temp and KvitnesetKlima are located in the same masts as Kvitneset. Kvitneset_Temp has inter-calibrated temperature sensors (PT100 from Campbell Scientific) at the same levels as the wind sensors, with a sampling rate of 0.2 Hz. KvitnesetKlima has measurements (1 Hz sampling rate) of temperature, dew point temperature, relative humidity and air pressure at 9 m above ground level (not corrected to mean sea level). Inter-calibrated Ttemperature measurements at 0.2 Hz (similar as at Kvitneset_Temp) are also done at four levels in the Trælbodneset mast, i.e. at the three levels with wind sensors as well as at 3 m above ground level (here named as Trælbodneset_temp). A Geonor T-200B precipitation gauge is installed at Brandal (cf. Fig. 2).

Storfjorden

Storfjorden is the name of the fjord system, which is divided into Sulafjorden, Hjørundfjorden and Vartdalsfjorden in addition to several other extensions further inland (Fig. 2). Sulafjorden is located approximately 10 km southwest from Ålesund between the islands Hareidlandet in the west and Sula in the east. The fjord is aligned along a south-southeast north-northwest axis, and it is ~12 km long from the mainland to the island Godøy and 3-6 km wide. Hareidlandet and Sula have steep mountains and their upper levels have an elevation of 500 – 700 m asl. In the south, Sulafjorden connects to Vartdalsfjorden, a long narrow fjord, which runs perpendicular to Sulafjorden, southwest to northeast. South of Vartdalsfjorden is Ørsta municipality with Sunnmørsalpene, a high and steep mountain region reaching more than 1200 masl. In the northeast, the narrow Hjørundfjorden connects to Storfjorden, running in a southeast - northwest direction. Figure 3 provides terrain profiles at all of the masts while Fig. 4 shows a photograph of Sulafjorden at the location of Kvitneset and Trælbodneset. The largest effort in the measurement campaign of the Coastal Highway E39 project in mid-Norway can be found here. An overview of the specific conditions at each mast is given below while details were presented in Haslerud (2019) and references therein.

Sulafjorden

A precipitation station and four tall meteorological masts are located in- Sulafjorden. The masts are located near both ends of two possible fjord crossing locations. Kvitneset and Langeneset on the western side and Trælbodneset and Kårsteinen on the eastern side.

The mast at Kvitneset is located on the headland Kvitneset on the northeast corner of Hareidlandet. The headland is a 300 m wide and 200 m long relatively flat area just below steep mountains reaching up more than 500 m over a distance of 1 km in the southwest. Figure 3 shows the terrain profile along a section through the locations at Kvitneset and Trælbodneset, and serves to highlight the steepness and height of the surrounding mountains. The masts are located at 6 m asl, in a location open to the Norwegian Sea in the sector west-northwest to north-northwest. The 10-minute wind data availability is near 100 % for all sensors. There was sporadic loss of 10 Hz data before July 2017 and in March 2019 due to technical issues. The data availability for the other atmospheric variables is near 100% until December 2018 when it is 0.1-0.9% lower.

A precipitation station was put in operation in March 2018, in the village Brandal between Kvitneset and Langeneset. Due to a fault, precipitation was not registered during the last 10 days of August 2018.

The Langeneset mast is located to the south in Sulafjorden (i.e. inward) from the mast at Kvitneset. It is mounted in a 100 m wide industrial area, below with a very steep mountain side (cf. Fig. 3). The slope is partly covered with an open forest and there are low buildings in the industrial area. Due to sporadic losses and mast downtime in the summer of 2017 data acquisition duringover the first year was 94.6%. For 2018 and onwards the data availability is close togood (100 %).

The mast at Trælbodneset is located at 12 m asl, on a small headland on the western side of the island Sula, with view to the open sea towards the westnorthwest. Towards the east, a mountain rises 450 m over a distance of 1 km (Fig. 3). The vegetation is relatively sparse at the mast and along the coast, while the mountainside has open forest. The 10-minute availability is 99 - 100% but the top sensor had a slightly later start than the other sensors (16 January 2018). The overall availability of 10 Hz data is good, with a somewhat reduced availability during some winter months. The 10-minute availability of the temperature sensors in the masts is near 100 % the first two years, then 92.1 and 97.2 % in 2019 and 2020.

The mast at Kårsteinen is also located on a small headland with a steep mountain rising to 660 m in the northeastern quadrant (Fig. 2). The mast is located near the opening of Sulafjorden into Vartdalsfjorden. Due to defect hardware, the availability was poor during the first few months of operation, but it is near 100% after February 2018. The availability of 10 H~~h~~z data is generally good, but relatively low in September 2018.

Vartdalsfjorden

The mast at Rjåneset is located at the tip of a small peninsula, just west of the settlement at Grøvika, on the southeastern shore of Vartdalsfjorden. There is a mountain rising to 1035 m a few kilometers to the east (Fig. 3), with steep mountainsides in the sector from north - northeast to east, and some of them across the fjord. The headland has some trees and the mountainside is forested. There are some low islands a couple of kilometres to the south and southeast. There are steep mountains across the fjord to the north and west, while the fjord is more open to the southwest where it meets Rovdefjorden and Voldsfjorden. The availability of 10-minute data from the top-most sensor is close to 100 % for the whole measurement period, while due to hardware issues, some data were lost for all sensors during September - November 2018, and after April 2019. The availability of the 10 Hz raw data is generally good, with sporadic losses during summer and slightly increase in the losses during late autumn for both years (2018 and 2019).

Hjørundfjorden

The mast at Gjeveneset is relatively low compared to the other masts, and is located at a potential building site for the components of a floating structure~~bridge components~~. ~~Gjeveneset~~ The mast is situated at the inlet of Hjørundfjorden at 3 m asl just by the sea, southwest of Hundeidvik, where the fjord opens up towards the north before meeting Storfjorden (Fig. 2). The mast is facing the fjord in the sector south-southeast over west to north, and the land is fairly open towards northeast with spread buildings within a few hundred metres. In the east, open terrain slopes gently up to 20 m over a distance of 200 m and then more steeply up to above 600 m over a distance of 600 m. On both sides of the fjord, steep mountains raise up to more than 1000 m asl. The headland has areas of trees and the mountain side is covered by forest. Data availability from the mast was just over 90% in 2019 due to a hardware failure in the spring. In 2018 and 2020 the availability was good (100%).

Julsundet

Julsundet is the sound that connects Molde and Fræna municipality on the southeast side and the island municipalities Midsund and Aukra on the northwest side. Julsundet is approximately 17 km long and runs in a north-south direction. On the south side, the sound opens into Moldefjorden, and on the north side into Harøyfjorden. A bridge ~~is planned~~ in the narrowmost part of the sound has been considered, where the width is 2.5 km and mountains reach up to 500 – 600 m on both sides, as seen in Fig. 5 and Fig. 6. Two masts, Midsund (dismantled in spring 2019) and Nautneset, are placed on the western side and one, Julbø, on the eastern side of Julsundet (Fig. 5). The masts at Midsund and Nautneset are only separated by a horizontal distance of ~100 m and have sensors at the same height over mean sea level as well as the same height over ground level. More details are given in Eriksen (2019), and references therein.

Julbø mast is placed on a low headland reaching fairly far into the sound. The topography on the headland goes up to 8 m while the mast is located at 4 masl. There are a few trees and a small cliff down to the sea on the southwest side. The monthly 10-minute data availability is near 100% except during periods associated with technical failures in May, July, November and December 2014, March and July 2017. The 10 hz data availability is generally good, with greater loss during the previously mentioned months.

The Midsund mast was mounted on the west side of the sound, on the Nautneset headland. The headland is forest covered and reaches roughly 300 m into the sound. The topography at the headland reaches up to 50 m with steep cliffs up from the sea. To the west of the headland the terrain rises steeply to 600 m. The mast was mounted 100 m from the outer headland at 24 m asl. The monthly 10-minute data availability is 99 - 100% and the 10 Hz availability typically high, except during periods associated with technical failures in March and August 2014, May and July 2017, as well as June 2018. The Nautneset mast is placed on the harbour about 100 m east of the location of the Midsund mast. The mast has free sight from north (360°) over east to south (180°). In the west the topography rises steeply to Midsund mast and further towards the mountains. In November 2016 - January 2017 the two topmost sensors were out due to a lightning strike, but the lowermost sensor operated normally, and in March 2019 a technical failure caused loss of data. Apart from this, the data availability has been close to 100%.

Halsafjorden

The Halsafjorden fjord runs in a southeast - northwest direction from Todalen in the south, towards the island Tustna (Fig. 7). The fjord is roughly 2.5 km wide at the planned bridge location. The terrain reaches up to 200 – 500 m asl on both sides and the sides are covered by forest (Fig. 7 and Fig. 8). A mast is placed at Halsaneset on the western side and another, Åkvik, is placed on the eastern side of the fjord. More details are given in Eriksen (2019), and references therein.

Halsaneset mast is mounted 10 masl, at tip of the headland Halsaneset which reaches 500 m out into Halsafjorden. There are two small, forested hills (15 and 40 m) on the headland, while the tip of the headland is more sparsely vegetated.

The Åkvik mast is mounted at 6 masl on the tip of a 200 m wide and 500 m long and forest covered headland, Orneset, on the eastern side of Halsafjorden. The headland is about 80 m high at the farm Haugen and slopes gradually towards the tip while the southern side of the headland is steep. The height of the mast at Åkvik was increased to 100 m in May 2020 and at the same time the station got a new name, Åkvik2, and observations stopped at the original station. Due to the short observation series at Åkvik2, no observations from the station are presented here. Both the Halsaneset and Åkvik masts have a high annual data-availability of 99.8-100% for 2016-2020.

3 Data handling and qQuality assurance

~~Monthly data files are available from Arctic Data Centre (ADC) (adc.met.no) https://doi.org/10.21343/z9n1-qw63. They are registered as a data collection, as it is a dynamic data set which is growing in time.~~

Data from the sites is handled as follows. Observational data is transmitted in near-realtime to KVT, with a temporary backup locally stored in the mast loggers. Data is processed and quality checked on an hourly basis at KVT. ~~The operational filtering of the 10 Hz wind data includes identifying and removing noise and data spikes in the dataset, as well as locked values, i.e. repeated and identical measurement values for the three wind components.~~ As the mast measurements are ongoing and instruments may need replacing, the filtering process is monitored and improved when the need arises. Furthermore, the operations of the mast observations are monitored in real-time by an automated system which warns about delays in observations, malfunctioning instruments, missing data or unphysical observed values.

The operational filtering of the 10 Hz wind data made publicly available is threefold. Unphysical values exceeding the specifications of anemometers are flagged. Noise and data spikes associated with unphysical jumps in the measurement values are identified and removed from the dataset using a method similar to median filtering. Locked values, i.e. repeated and identical measurement values for the three wind components, are removed. Further filtering of the available 10 Hz dataset is not done, and it is left to the user of the data to employ more stringent filtering routines, as he sees fit and needed for the intended use of the data. Suggestions on applicable filtering methodologies and additional quality assurance are e.g. given in Hubbard et al. (2012), with more specific details given in in Capozzi et al. (2020) and Steinacker et al. (2011). ~~During the filtering, t~~After filtering, ~~he~~ the observed wind direction in the 10 Hz data is rotated towards true ~~correct~~ north, and 10-minute means are produced from the 10 Hz wind data. There is no minimum on the amount of 10 Hz samples used in producing the 10-minute averages, but the amount can be deduced by inspection of the available 10 Hz data. For other data than observations of wind, the raw-data are made available as is, and only a first screening of the data is done, with no additional filtering performed.

Hourly ~~The resulting files for~~ data at the native sampling rate~~both 10 Hz~~ and with 10-minute sampling is written to files (netCDF4-format), and are sent to a virtual server belonging to MET Norway via sftp ~~as soon as they are ready~~, typically on a hourly or daily basis. MET Norway performs an additional quality check~~control~~ on the data, to track any inconsistencies and ~~and to track any~~ delays in the data stream. Data from the masts are published as open access on "http://thredds.met.no". THREDDS (Thematic Real-time Environmental Distributed Data Services) is software solution run on ~~a~~ web servers that provides metadata and data access for scientific datasets, using a variety of remote data access protocols such as OPeNDAP (Open-source Project for a Network Data Access Protocol). Due to the high data amount for the 10 Hz wind data, the 10-minute data are stored ~~in~~ separately ~~netCDF-files~~. Both type **of** files include wind speed, wind direction and vertical wind speed. The 10-minute averages of the wind observations are based on 10 Hz data from the interval preceding ~~Wind speed is the average of the 10-minute of 10 Hz data previous to~~ the time stamp (i.e. labelled right), while the interval is open on the left side and closed on the right side (i.e. the end points only includes the observation concurrent with the time stamp).~~Precipitation data from Brandal station is available on the API (Application Programming Interface) frost.met.no with station number 59570.~~

~~The long term automatic weather station Ona II (an island station just of the coast, Fig. 1) is used as a reference station for the wind and temperature measurements. Ona II is operated by MET Norway and data are available from the open data API frost.met.no. Wind speed and direction from an 18 years climatological period from 2001.04.01 to 2019.03.31 are presented here. The meteorological station Ålesund (Nørve, no. 60945) has been operational since 2009 and is used as a reference for precipitation.~~

4 Wind ~~climate~~ conditions and data overview during observation period

The long term automatic weather station Ona II (MET station number 62480) at the island Ona just off the coast (Fig. 1) is used as a reference station for the wind and temperature measurements. Ona II is operated by MET Norway and data are available from the open data API: "frost.met.no" ~~t,OnaClimatologically at~~. Houry observations of wind speed and direction are available since 2001, and they are used to provide a description of the current state of the regional wind climate, which is well described by approximately 18 years of data. For this period, the median wind speed at Ona is 6.6 ms^{-1} which varies from 5.1 ms^{-1} in August up to 8.7 ~~8-9~~ms^{-1} in January ~~August during July and ms^{-1} 5-6 down to with the highest recorded wind speeds of in December and January~~ (Fig. 9). Winds above 30 ms^{-1} have been observed~~are recorded~~ in the autumn and early winter, i.e. from September to December. Since the fjord crossings are separate projects with different timelines and since permits for mounting the masts are granted separately, all the masts were erected at different times from 11 February 2014 in Julsundet to 14 March 2018 in Hjørundfjord. ~~Using~~A ~~a~~ 3-year period from Ona II is chosen~~, 1 April 2016 to 31 March 2019,~~ to represent the period with fjord measurements (Fig. 10 top left). When compared to the wind speed distribution for the reference period of 18 years (Fig. 9) we see that the wind ~~climate during measurement period~~ has been ~~slightly~~somewhat weaker ~~during the measurement period than usual (fig. 10 top left) calmer~~during the the chosen 3 years than during the reference period. The median and 75th percentiles of wind speed during February, July and November ~~is~~ are lower than ~~normal~~ for the whole full series and there ~~has~~have been no recordings of wind speed above 30 ms^{-1}.

At the 11 stations discussed here (Table 2), the lowest annual median wind speed is found in the inner part of Sulafjorden at Langeneset (2.95 ms^{-1}) and Kårsteinen (2.39 ms^{-1}) while median wind speed above 5 ms^{-1} are recorded in Julbø (5.15 ms^{-1}), Kvitneset (5.03 ms^{-1}), and Rjåneset (5.04 ms^{-1}). Strong winds are most frequent in Julsundet and at Kvitneset in Sulafjorden, while t~~T~~he highest 99th percentiles ~~data~~ are found in the inner part of the fjords (Gjeveneset and Rjåneset) in spite of their lower measurement heights. This is presumably related to the local topography and how well the sites are exposed to direction associated with strong winds. ~~-~~The 99th percentile~~ data~~ for the, separately, upwards and downwards, oriented vertical winds, indicates that the strong vertical gusts are often found at the stations in Sulafjorden as well as at Nautneset, compared to at the other stations, especially ~~at the stations~~those in Halsafjorden.

The wind speed shows a clear seasonal variation at the Ona reference station and most of the masts, except Trælbodneset, Kårsteinen, Gjeveneset and Rjåneset (Fig. 9 and Fig. 10). Here, the time series are short, and the statistics ~~more un~~are less reliable. ~~From these plots, the stronger wind climate is found in Julsundet and at Kvitneset in Sulafjorden, but episodically the winds in the fjords are stronger, as seen in Table 2.~~

The wind roses ~~The wind roses~~ for the ~~from~~ Ona reference station (Fig. 9 and top left in Fig. 11~~0~~)~~ period of 18 years climatological for the as well as for a 3 year period overlapping with the mast observations~~ show that the directional distribution during the 3 year period is quite typical for the climate conditions during the last 18 years, as would be expected at a site where the low-level flow is strongly affected by both the local terrain as well as the large scale orography of western Norway. They also show that along the coast, the ~~, shows that winds are~~ most~~most~~ frequent, as well as the~~ and~~ strongest, winds are from the southwest and the northeast, following the general orientation of the coast.~~-~~ The synoptic scale flow aloft has a large contribution from the south and the east, as well as a component from the northwest, but the orographic forcing typically deflects such flow along the large scale orography (see Barstad and Grønås, 2005, and references therein). The wind roses covering the full observation period until april 2019 (Fig~~ure~~. 11) for the 11 stations indicate flow which is strongly affected by the local terrain. Southerly winds (winds blowing towards the sea) are frequent at all stations, and dominant at Julsundet, Halsafjorden, Trælbodneset, Gjeveneset and Rjåneset. The strongest winds are also typically associated with southerly flow. While northeasterly winds are frequent at Ona, the local terrain forcing at many of the observation sites typically stagnates such larger-scale flow, or rotates it along the main fjord axes. Furthermore, northeasterly flow at Ona is presumably a result of large scale synoptic flow from a wide sector covering flow from the northwest to the northeast, and will hence be associated with different wind directions at each site. The sites most exposed to northeasterly flow are Åkvik, Gjeveneset and Rjåneset, while frequent and strong northerly flow is in fact found at most of the sites, e.g. in Julsundet. In order to facilitate a more direct comparison of the wind conditions at the sites and the variation within the region, wind roses from Ona and the sites, based on data for 1 year, are shown in Fig. 12. Only concurrent data is used for the roses in individual panels, i.e. short periods of downtime are removed for all sites in the same fjord. The wind roses are overlaid on the topography and highlight in a qualitatively manner the strong topographic forcing at low-levels in the fjords, as well as the large regional variations in the wind conditions for the given year. The similarity of the wind roses for Ona in Figs. 9, 11 and 12 implies that the same spatial variations exist in the regional wind climate, as for the 1 year period used in Fig. 12.

The monthly temperature, observed at the top most sensor in the Kvitneset mast is shown in Fig. 13~~2~~, in addition to temperature observations from the Ona II reference station. ~~-~~There are on average small differences between the monthly temperature at both sites, with most notable difference being that the maximum temperature is typically 1-3°C higher at Kvitneset than at Ona. The observed mean monthly temperatures are also quite similar to the climatological mean from the 18 year~~s~~ ~~climatological~~ period~~ at Ona II~~. The most notable differences are that April, July and November 2018, as well as 2019 were 1-2°C warmer than average, while March 2019 was ~2°C colder. To illustrate some of the details in the data, the temperature and wind at Kvitneset during the early part of a varm day on 28 July 2018 are shown in Fig. 14. There was a high pressure over the Kola peninsula and a low pressure system over the british isles, giving rise to the easterly advection of warm air which was ~20°C at 850 hPa (not shown). Skies were clear and there was presumably a large scale subsidence in the lee of the mountains of west and mid Norway. The wind was southerly and weakening during the early hours of 28 July 2018, and the lowest temperature was measured at 9 m a.g.l and the highest temperature at the top of the mast. This is indicative of a very stable boundary layer, which is cooled from below by radiatiative cooling as well as the sensible heat flux between the ocean surface and the surface layer. There are large oscillations in the temperature at upper levels, especially between 6 UTC and 8:20. These are presumably associated with the advection of warm air, which is detached from the colder air below. The top sensors are within this warm layer for long periods while the depth of the layer varies such that the sensors at 44 m and 71 m are only located inside this layer for short periods of time. The wind speed starts to increase and the vertical mixing increases between 7 and 8 UTC, and at 8:30 the colder surface air appears to be mixed up to at least 100 m but the layer is however still stably stratified. Weak winds and a varying wind direction are associated with the period of strongest solar heating from 9 until the early afternoon. There is a gradual warming of the whole layer until 12 (noon) at which time the whole layer is well mixed or only weakly stably stratified, and the wind speed has increased at many of the masts. Large variations in the vertical velocity at the top sensor appear to be associated with periods of increased mechanical and convective mixing, in particular between 10 and 11 UTC.

). This may be related to the proximity to the steep and high mountains at Brandal, stronger forced uplift during northerly flow and more spillover during southerly flow.
3Brandal station located in Sulafjorden reveals much higher precipitation than what is recorded at Nørve, both when comparing to the climatology based on 10 years but also within the same year (Fig. 1
Masts on both sides of the fjords allow for investigation of the simultaneous differences in the wind field on each side of the fjord. An example is given for Halsafjorden in the wind variation across Halsafjorden is shown in (Fig. 154). The mean wind speed is stronger at Åkvik than at Halsaneset for all wind directions except for winds from the south. The strongest winds observed at the masts are observed at Halsaneset during southerly winds, while winds are strongest at Åkvik during northwesterly flow. This is a result of the orographic forcing as well as the orientation of the fjord main axis. The mountain south of the Åkvik mast presumably introduces som sheltering while northwesterly flow may be accelerated somewhat along the terrain on the eastern side of the fjord.

As the full 3-dimensional wind vector is observed with a temporal frequency of 10 Hz, the turbulence spectral density can be estimated. An arbitrary example of such an estimate is given in Fig. 165, based on observations of a northerly storm at 50 m in the Julbø mast . The analysis is , based on observations from a 20-minute period starting atpreceding 13:40 UTC on 1 January 2019, and shows the power spectral density for the along flow component of the turbulence at the Julbø mast during a northerly storm. The horizontal wind vector has previously been is decomposed in components oriented rotated along the mean wind direction, as well as perpendicular to it. The wind speed data and the are linearly detrended to ensure the stationarity of the wind data and smoothed to reduce effects from the sharp interval boundary. The spectral density is calculated using a fast Fourier transformation, implemented in a periodogram-method in a standard signal processing package (scipy, 2020) in the python programming language. The blue dots are the spectral energy density at individual frequencies while a 100 point running mean provides a smoother represantation of the results. The reduction in energy density with higher frequency has a analyzed spectra has a similar slope as indicated by the -5/3 power law for turbulence spectra, i.e. as indicated by the theoretical predicion of Kolmogorov (1941).he -5/3 power law for turbulence spectra. This is as expected and typical for turbulent flow at the site.

The meteorological station Ålesund (Nørve, no. 60945) has been operational since 2009 and is used as a reference for precipitation. Brandal station located in Sulafjorden reveals much higher precipitation than what is recorded at Nørve, both when comparing to the climatology based on 10 years but also within the same year (Fig. 17). This may be related to the proximity to the steep and high mountains at Brandal, stronger forced uplift during northerly flow and more spillover during southerly flow.

5 Data accessavailability

The data are available on the MET Norway API frost.met.no (precipitation measurements at Brandal II with station number 59570) and from Arctic Data Centre (ADC): at https://adc.met.no/datasets/"DOI: 10.21343/z9n1-qw63" (Furevik et al., 2019). They are registered as a data collection, as it is a dynamic data set which is growing in time. The data is typically updated on a daily basis, but data missing in the first dissemination to the server are typically available with a lag of 1 - 3 months.

The data on ADC are posted as a file for the raw data (10 Hz) and a file for the 10-minute mean wind speed, separately for each mast and every each month. Each file contains data from the different heights at the specific mast, including selfdescribing metadata, such as geographical location and sensor heights. Temperature at different heights is also posted for each month for two~~each ~~ mast (Kvitneset and Trælbodneset~~) where it is available (~~, files of type temp_0p2hz). Additional meteorological data from the weather mast at Kvitneset, i.e. tMetpack_1hz (temperature), prsMetpack_1hz (air pressure), dewpointMetpack_1hz (dew point temperature), RHMetpack_1hz (relative humidity) are posted in files with KvitnesetKlima in the file name.

6 Summary

We have presented the atmospheric part of a ~~A~~ unique, and large, atmospheric and oceanic dataset, which is presently being built~~,~~ in connection with several planned fjord crossings in the Coastal Highway E39 - project of the NPRA. The atmospheric part of this measurement programme includes wind observations in 1~~1~~2 tall masts in the three different fjord systems of Mid-Norway, and it started in 2014 and is presently ongoing. The overall data return is 98.9 %. The data collection is described, including a short summary of the geography at the sites. Examples of observed parameters are presented and put in context with observations and climatology from reference weather stations. The examples illustrate the quality of the data, but also a strong influence of the steep terrain on the wind measurements from these land-based masts. In addition to local design and planning of infrastructure, the data collection may ~~is~~be useful for investigation of boundary flow in complex terrain, and for verification of numerical modelling~~ in that respect~~. In combination with remote sensing and oceanographic data from ~~the ~~buoys deployed in the project, it offers a solid basis for the study of a fjord system over at least a decade. The data collection may furthermore be useful for the industry or in other fields of research, where wind climate is of importance.

Author contributions. B. R. Furevik is responsible for publication of the data set and writing of the manuscript together with H. Ágústson. H. Ágústson is responsible for the first line of quality control and a systematic analysis of the dataset,~~ and~~ as well as processing of files into netCDF-format and transfer to MET Norway. A. L. Borg is responsible for further quality control of files, aggregation into monthly files and posting to the repository. B.R. Furevik, H. Ágústson and Z. Midjiyawa made the analyses presented in this paper. F. Nyhammer is responsible for the design, deployment and maintainance of the masts and instrumentation. M. Gausen is in charge of the measurement campaign for the Coastal Highway E39 project in Mid-Norway.

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References

Andersen, O. J., and Løvseth, J.: Gale force maritime wind. The Frøya data base. Part 1: Sites and instrumentation. Review of the data base, Journal of Wind Engineering and Industrial Aerodynamics, 57, 97-109, ~~https://doi.org/~~ DOI:10.1016/0167-6105(94)00101-I, 1995.

Andersen, O. J., and Løvseth, J.: The Frøya database and maritime boundary layer wind description, Marine Structures, 19, 173-192, doi: 10.1016/j.marstruc.2006.07.003, 2006.

Barstad, I. and Grønås, S.: Southwesterly flows over southern Norway-Mesoscale sensitivity to large-scale wind direction and speed. Tellus A. 57, 136-152, 2005, DOI: 10.3402/tellusa.v57i2.14627.

Capozzi, V., Cotroneo, Y., Castagno, P., De Vivo, C., and Budillon, G.: Rescue and quality control of sub-daily meteorological data collected at Montevergine Observatory (Southern Apennines), 1884–1963, Earth Syst. Sci. Data, 12, 1467–1487, DOI: 10.5194/essd-12-1467-2020, 2020.

Eriksen, O. K.: E39, brukrysninger Julsundet og Halsafjorden, Møre og Romsdal, statusrapport for vindmålinger pr juni 2019, Kjeller Vindteknikk, Lillestrøm, Norway, Technical report KVT/OKE/2019/R080, 38, 2019.

Furevik, B. R., Ágústsson, H., Lauen Borg, A., Nyhammer, F.: The E39 coastal highway observational dataset – atmospheric flow in complex coastal terrain in Mid-Norway, Norwegian Meteorological Institute. https://doi.org/DOI: 10.21343/z9n1-qw63, 2019.

Gill Instruments: Software bug affecting ‘w’ wind component of the WindMaster family, Technical key note, Open File Key note series number KN1509v6, http://gillinstruments.com/data/manuals/KN1509-WM-WMPro-W-Bug-Info-Sheet.pdf, accessed February 2020, 6 pp., 2016.

Godø, O. R., Johnsen, S., and Torkelsen, T.: The LoVe Ocean Observatory is in Operation, Marine Technology Society Journal, 48, 24-30, https://doi.org/DOI: 10.4031/MTSJ.48.2.2, 2014.

Haslerud, A. S.: Analysis of wind measurements from 6 masts at Sulafjorden 24.11.2016-31.03.2019, Kjeller Vindteknikk, Technical report KVT/ASH/2019/R033, 292 pp., 2019.

Haslerud, A. S. and Ágústsson, H.: Analysis of wind measurements from 6 masts at Sulafjorden 24.11.2016-30.09.2018, Kjeller Vindteknikk, Lillestrøm, Norway, Technical report RAP-KVT-L-102 / KVT/ASH/2018/R108, 107 pp., 2018.

Hubbard, K., You, J., and Shulski, M.: Toward a Better Quality Control of Weather Data,Practical Concepts of Quality Control, edited by: Saber, M. and Nezhad, F., ISBN: 978-953-51-0887-0, InTech, DOI: 10.5772/51632, 2012

Jonassen, M. O., Ólafsson, H. , Reuder, J. and Olseth, J. A.: Multi-scale variability of winds in the complex topography of southwestern Norway, Tellus A: Dynamic Meteorology and Oceanography, 64, 10.3402/tellusa.v64i0.11962, 2012.

Kolmogorov, A, 1941: The local structure of turbulence in incompressible viscous fluid for very large Reynolds' numbers. C. R. Acad. Sci., USSR, 30, 301 – 335.

Kristjánsson, J.E., Barstad, I. , Aspelien, T., Føre, I. , Godøy, Ø., Hov, Ø., Irvine, E., Iversen, T., Kolstad, E., Nordeng, T.E., McInnes, H., Randriamampianina, R., Reuder, J., Sætra, Ø., Shapiro, M., Spengler, T. and Ólafsson, H.: The Norwegian IPY–THORPEX: Polar Lows and Arctic Fronts during the 2008 Andøya Campaign, Bull. Amer. Meteor. Soc., 92, 1443–1466, https://doi.org/DOI: 10.1175/2011BAMS2901.1, 2011.

Norwegian Public Roads Administration (NPRA): Bruprosjektering. Prosjektering av bruer, ferjekaier og andre bærende konstruksjoner, Open File Håndbok N400, 175 pp., https://www.vegvesen.no/_attachment/865860/binary/1030718?fast_title=H%C3%A5ndbok+N400+Bruprosjektering.pdf, accessed 1 November 2019, 2015.

Reigstad, M., Eldevik, T., and Gerland, S.: The Nansen legacy, Fram Forum 2019, Framsenteret AS, pp. 100-105, https://framsenteret.no/wp-content/uploads/2019/03/Framforum-2019-digital.pdf, 2019.

Renfrew, I.A., Moore, G.W., Kristjánsson, J.E., Ólafsson, H., Gray, S.L., Petersen, G.N., Bovis, K., Brown, P.R., Føre, I., Haine, T., Hay, C., Irvine, E.A., Lawrence, A., Ohigashi, T., Outten, S., Pickart, R.S., Shapiro, M., Sproson, D., Swinbank, R., Woolley, A., and Zhang, S.: The Greenland flow distorsion experiment, Bull. Amer. Meteor. Soc., 89, 1307–1324, https://doi.org/DOI: 10.1175/2008BAMS2508.1, 2008:

SciPy Documentation: https://docs.scipy.org/doc/scipy/reference/tutorial/signal.html (accessed February 2020)

Standard Norge, Actions and action effects, pp. 148, NORSOK N-003:2017, 2017.

Steinacker, R., Mayer, D., and Steiner, A.: Data Quality Control Based on Self-Consistency, Mon. Weather Rev., 139, 3974–3991, DOI: 10.1175/MWR-D-10-05024.1, 2011.

Steinhoff, T., Gkritzalis, T., Lauvset, S. K., Jones, S., Schuster, U., Olsen, A., Becker, M., Bozzano, R., Brunetti, F., Cantoni, C., Cardin, V., Diverrès, D., Fiedler, B., Fransson, A., Giani, M., Hartman, S., Hoppema, M., Jeansson, E., Johannessen, T., Kitidis, V., Körtzinger, A., Landa, C., Lefèvre, N., Luchetta, A., Naudts, L., Nightingale, P. D., Omar, A. M., Pensieri, S., Pfeil, B., Castaño-Primo, R., Rehder, G., Rutgersson, A., Sanders, R., Schewe, I., Siena, G., Skjelvan, I., Soltwedel, T., van Heuven, S., Watson, A.: Constraining the Oceanic Uptake and Fluxes of Greenhouse Gases by Building an Ocean Network of Certified Stations: The Ocean Component of the Integrated Carbon Observation System, ICOS-Oceans, Frontiers in Marine Science, 6, 544 pp., DOI: 10.3389/fmars.2019.00544, 2019.

Tallhaug, L.: E39, Julsundet, Midsund kommune - vibrasjonsmåling Nautneset. Kjeller Vindteknikk, Lillestrøm, Norway, Technical report KVT/LT/2017/R046, 5 pp., 2017.

Figure 1. Overview of a part of the Møre and Romsdal region (approximate location shown in the inset) and the location of the three areas where the meteorological masts are located (S, J and H). The locations of three national weather stations with long-term data available, are indicated with coloured circles. Map layers are © Kartverket and licensed under Creative commons version 4.

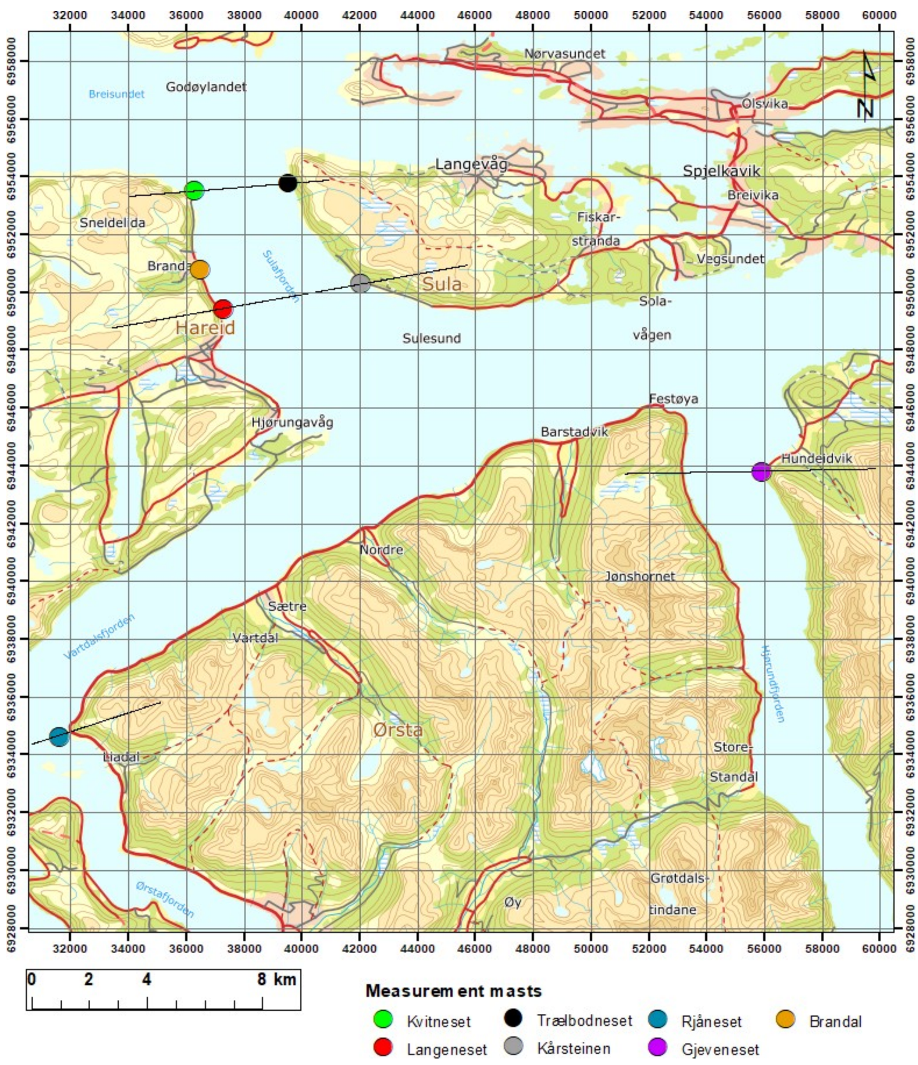


Figure 2. Map of Storfjorden fjord system with location of the seven observational sites and height profiles shown in Fig. 3. Map layers are © Kartverket and licensed under Creative commons version 4.

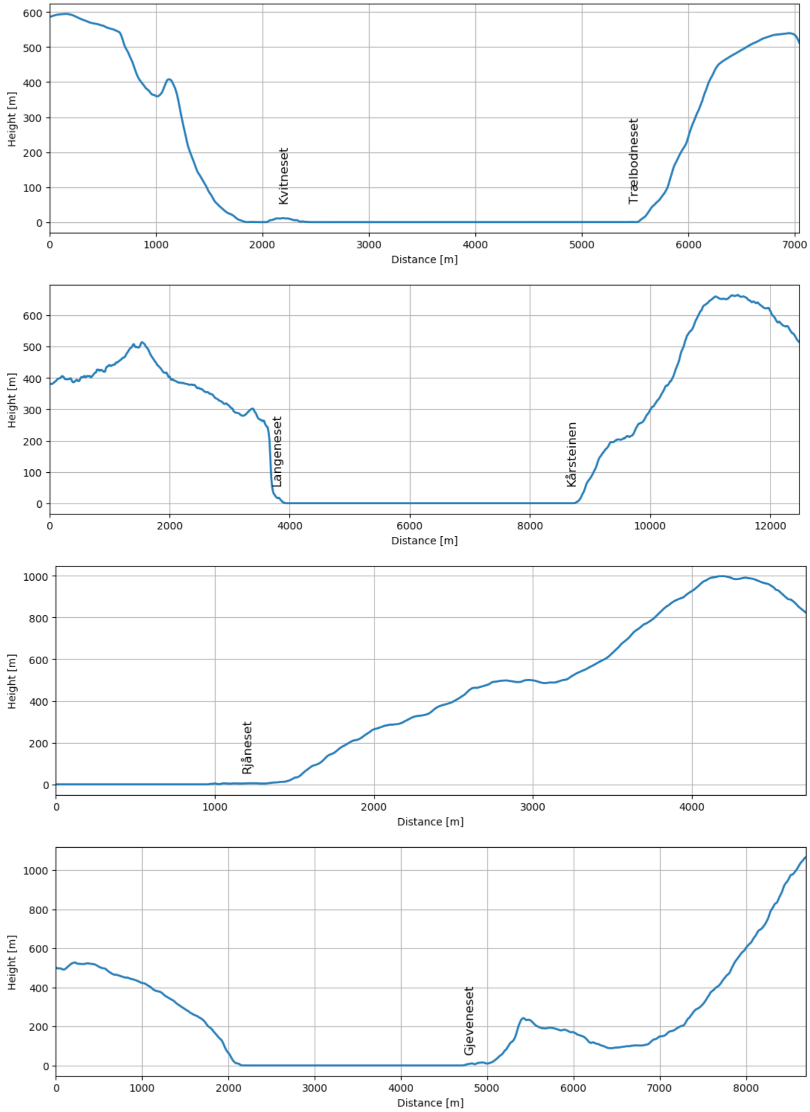


Figure 3. Terrain profiles along the sections indicated in Fig. 2, with the locations of the masts indicated. Terrain data are © Kartverket and licensed under Creative commons version 4.

Figure 4. Sulafjorden with the islands Hareidlandet, Godøy and Sula from left to right. Between Hareidlandet and Godøy is Breisundet, which is the main opening of the fjord system to the Norwegian Sea. Photograph taken on 13 October 2016.

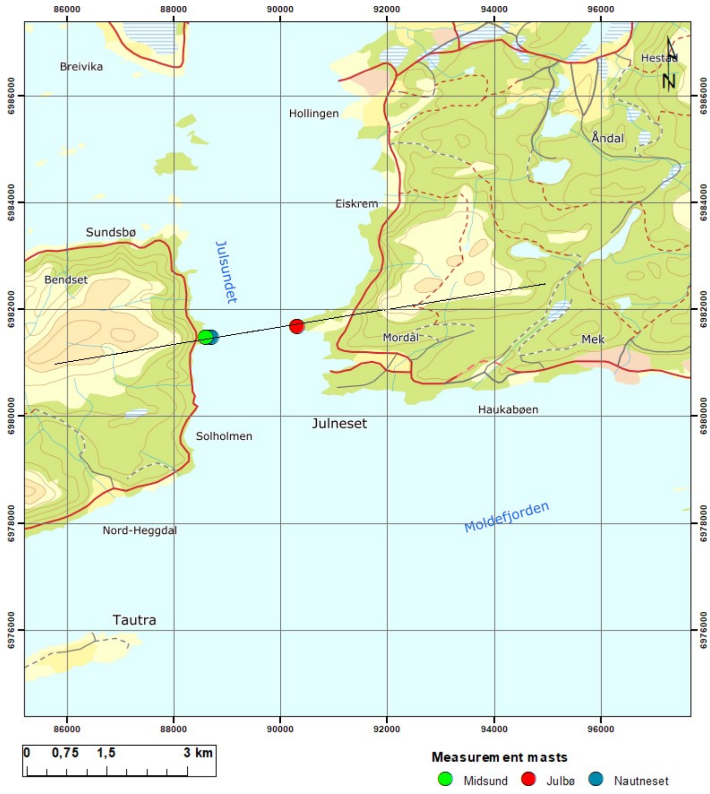


Figure 5. Map of Julsundet with location of meteorological masts and the height profile shown in Fig. 6. Map layers are © Kartverket and licensed under Creative commons version 4.

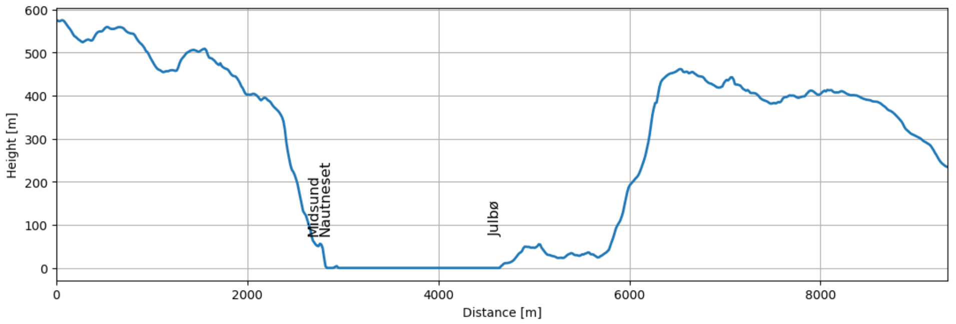


Figure 6 Terrain profiles along the sections indicated in Fig. 5, with the locations of the masts indicated. Terrain data are © Kartverket and licensed under Creative commons version 4.

Figure 7. Map of Halsafjorden with location of the meteorological masts, and the height profile shown in Fig. 8. The mast Åkvik2 is a contination of Åkvik and located at the exact same location. Map layers are © Kartverket and licensed under Creative commons version 4.

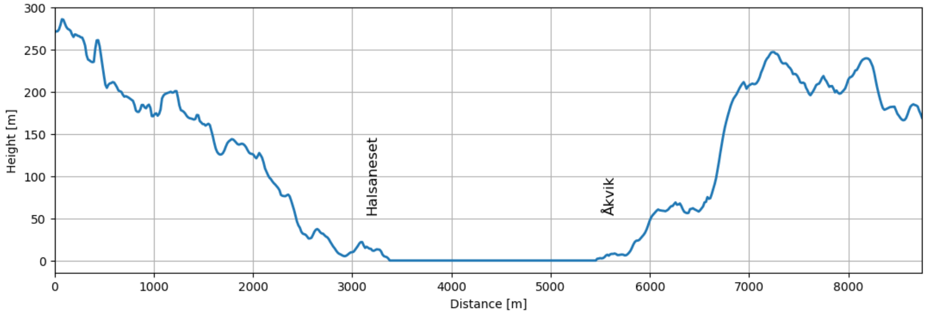


Figure 8 Terrain profiles along the sections indicated in Fig. 7, with the locations of the masts indicated. Terrain data are © Kartverket and licensed under Creative commons version 4.

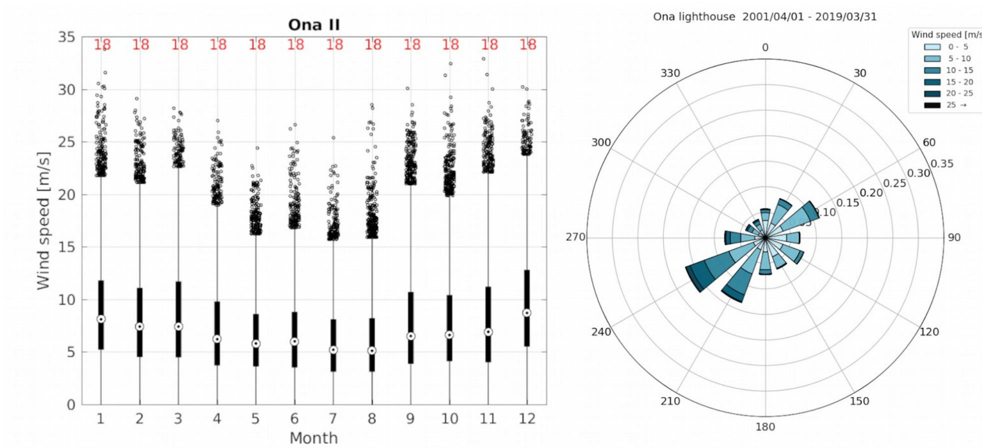


Figure 9. Wind statistics for the 18 year climatological period at Ona II. Left: Box plot of wind speed per month of the year. The boxes in the plots shows the 25/75 percentiles with the median value as a circle inside. The lines above and below (the whiskers) represent 1.5 interquartile range from the box. Values beyond this are plotted as dots above each line. The red numbers above each month, show the number of full months used to produce each box. Right: Wind rose showing the wind speed and direction distribution. The length and direction of the bar shows the directional distribution of the wind speed while the colour scale shows the wind speed distribution.

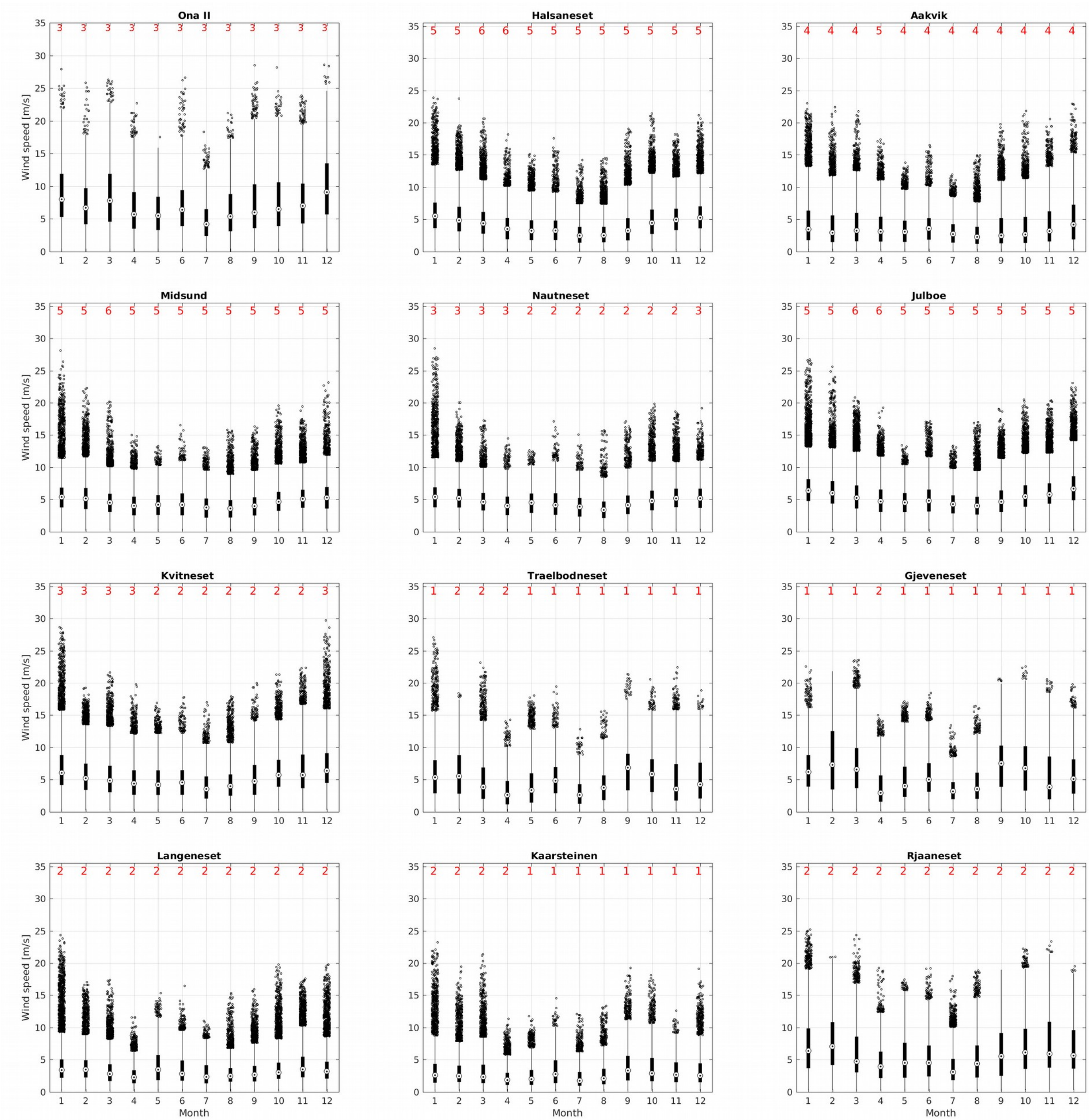


Figure 10. Box plots of wind speed per month of the year over three years from Ona II (reference station) and all available data the uppermost sensor at theon the 11 masts sites. The time periods for each panel are found in the corresponding panel in Fig. 11.

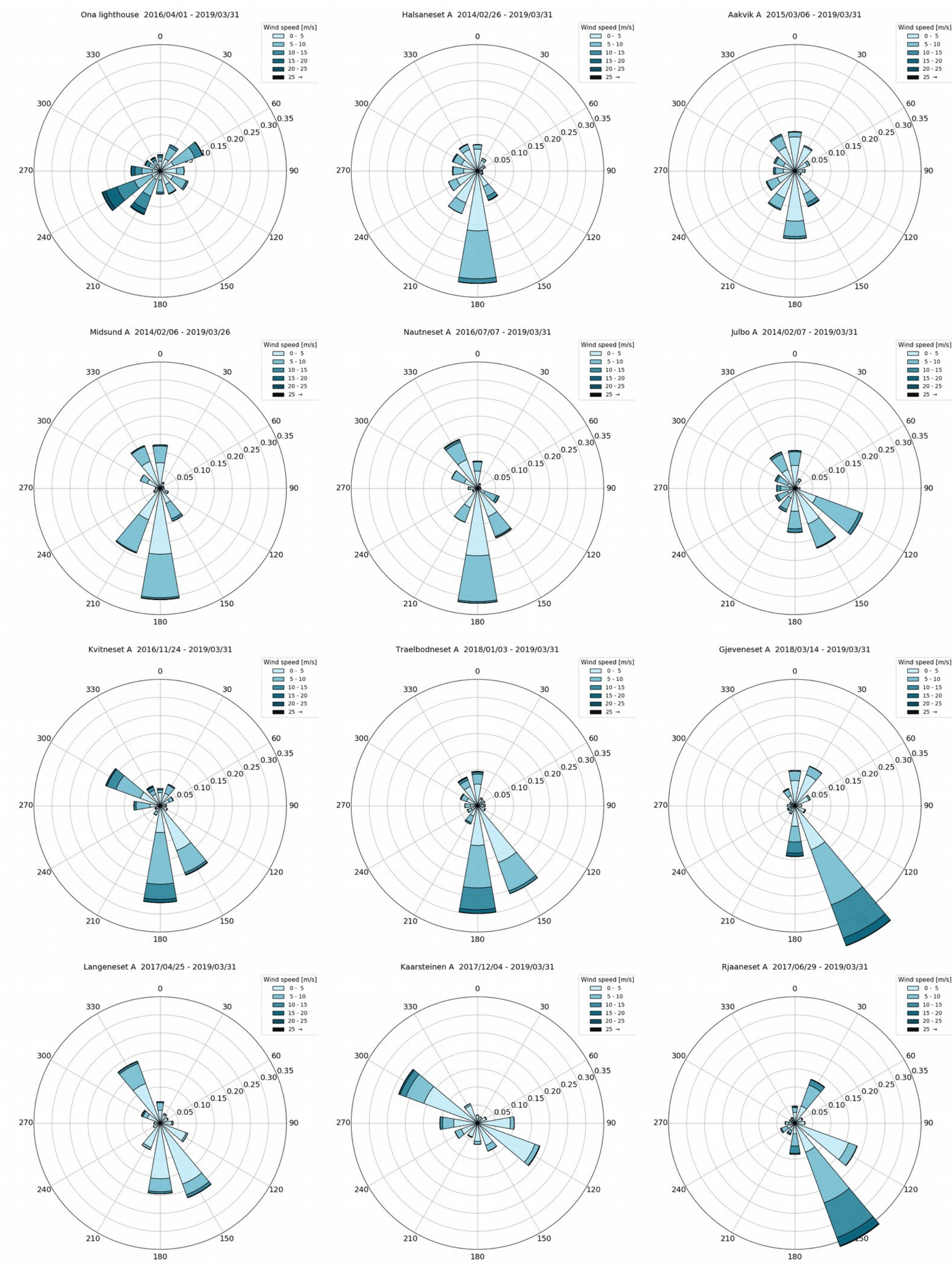


Figure 11. Wind roses showing the wind speed and direction distribution over three years from Ona II (reference station) and all available data from the uppermost sensor at the sites~~on the 11 masts~~.

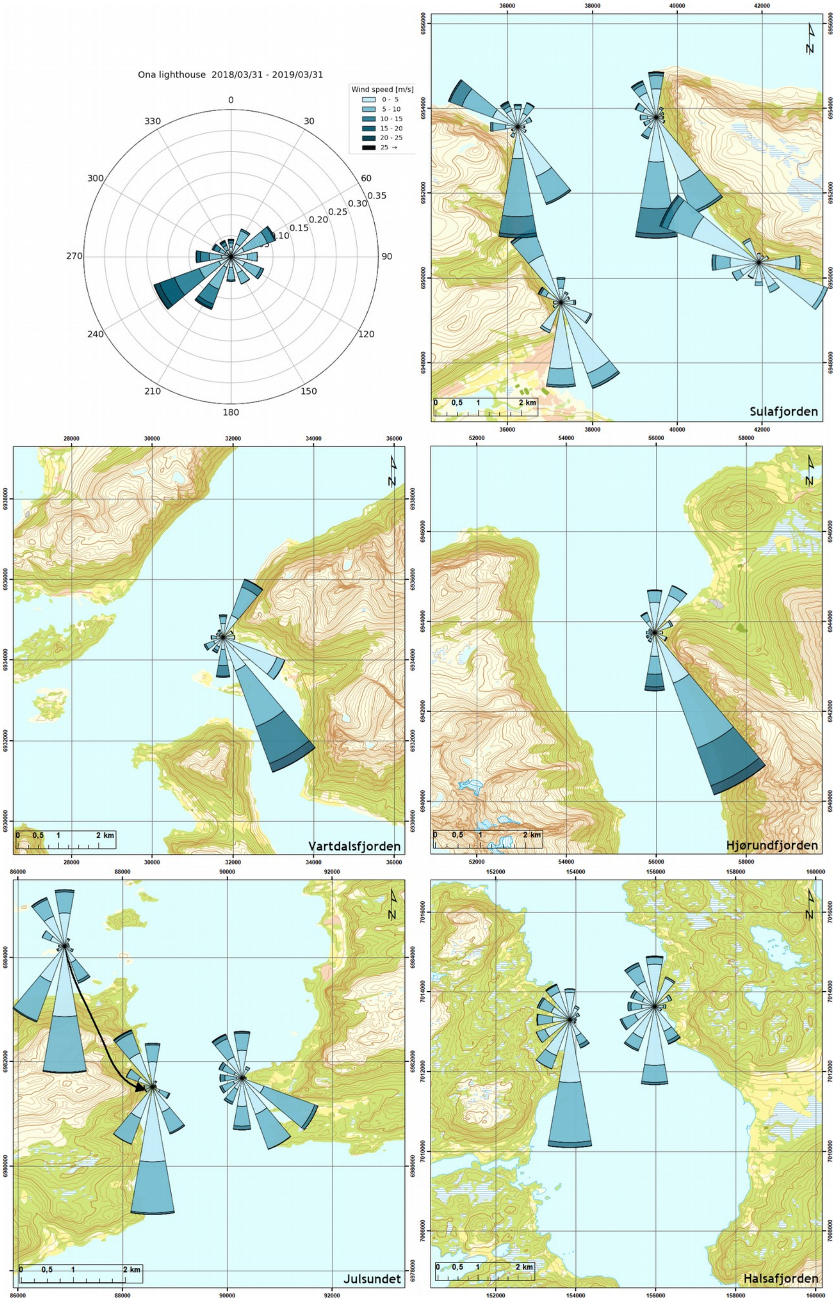


Figure 12. Wind roses from Ona and the top-sensor of at each site, overlaid on topographic maps. Only data from 1 March 2018 - 28 February 2019, at all the sites, are used to produce the wind roses. All the roses are in the same scale as the Ona wind rose (top left). Map layers are © Kartverket and licensed under Creative commons version 4.

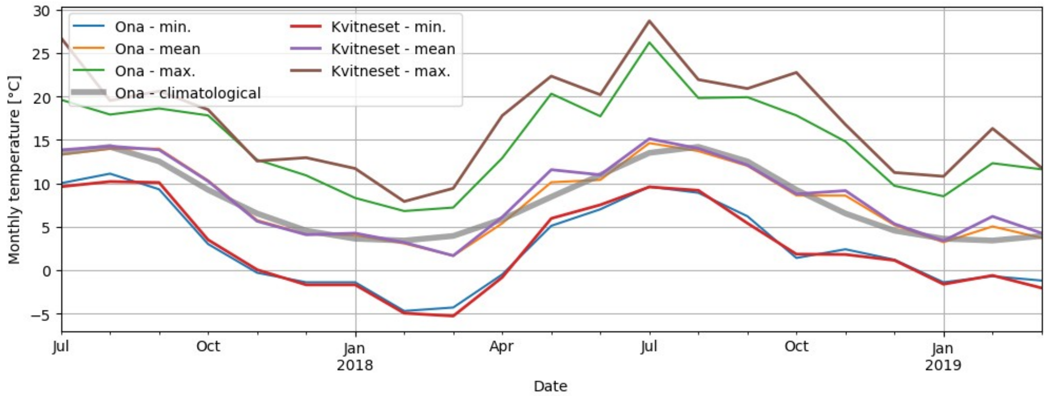
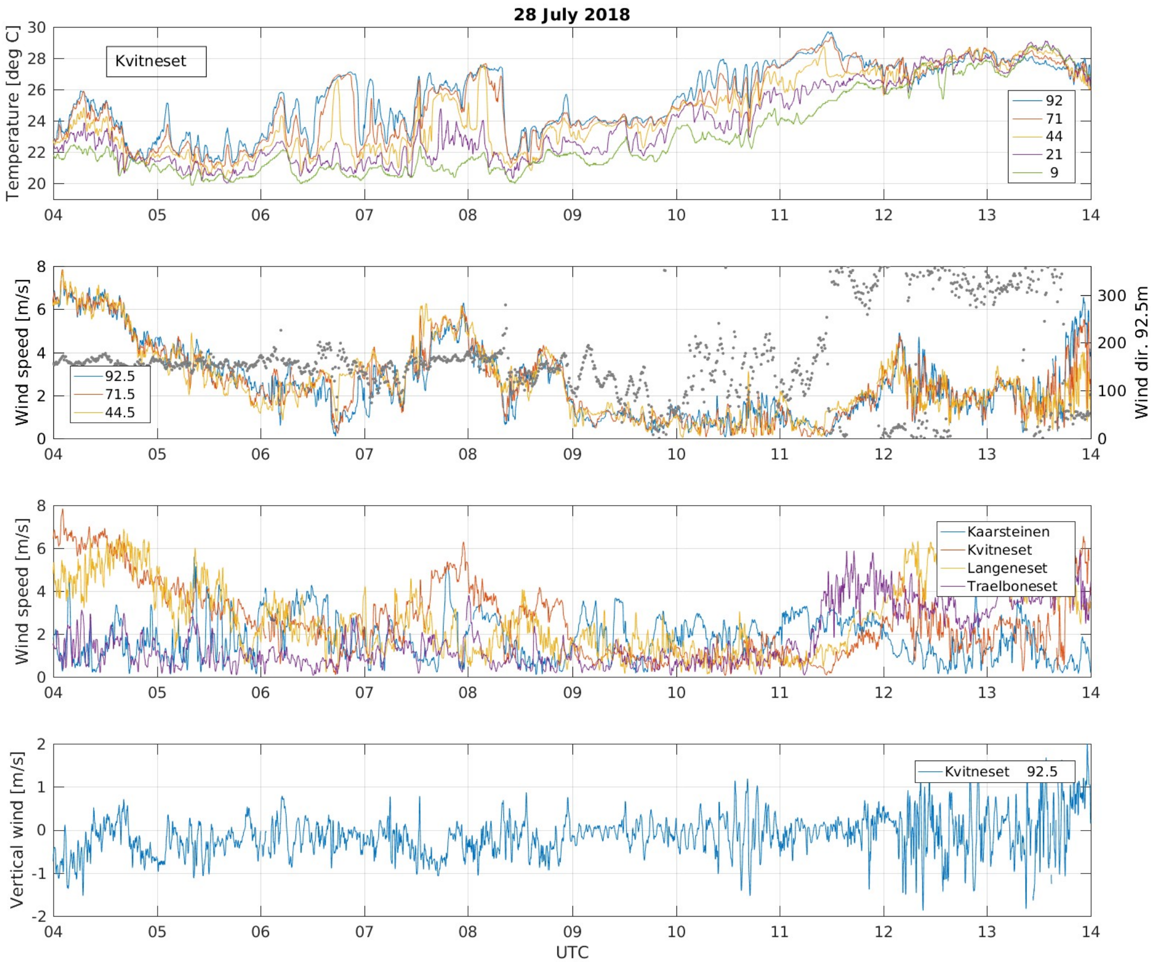


Figure 13~~2~~. Monthly mean, maximum and minimum temperature at top of Kvitneset mast and at the Ona reference meteorological station. Also shown is the ~~climatological~~mean temperature (thick gray line) at Ona, for ~~the~~a 18 year period.

~~. Monthly measured precipitation at Brandal (green), compared to the same period (blue) and climatology for 2009 - 2019 (orange) at the reference station Nørve in Ålesund.~~

~~3~~

~~Figure 1~~



<u>**Figure 14. Time series of temperature, wind direction, horizontal and vertical wind speed at Kvitneset (panel 1, 2 and 4 from top) and horizontal wind speed from the top sensor of all four masts in Sulafjorden (panel 3). Sensor heights at Kvitneset are given in the legends. The 10 Hz wind speed data are smoothed using a 30 s median filter.**</u>

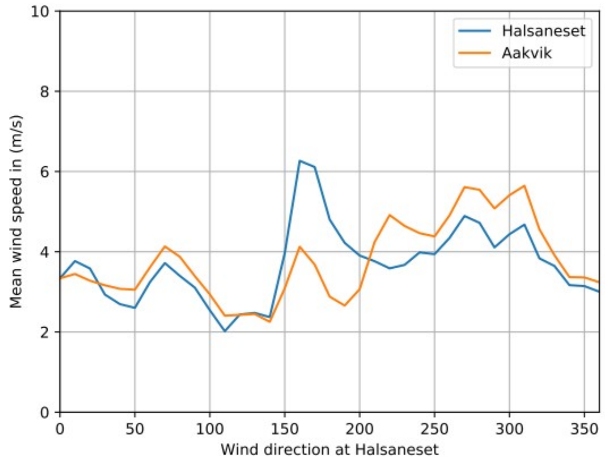


Figure 154. Wind speed variation at Halsaneset and Åkvik in Halsafjorden, as a function of wind direction at Halsaneset on the western side of the fjord. Based on 4 years of data (2016 - 2019).

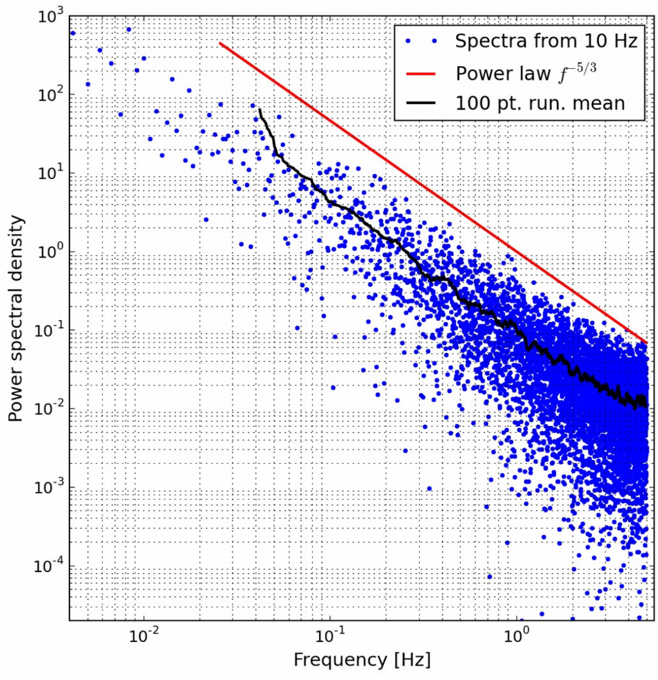


Figure 165. Example of turbulence spectra for the along wind component during a northerly storm with ~25 m/s mean wind at the top sensor of the Julbø mast. The spectra are analysed from the 20-minute period before 14:00 UTC on 1 January 2019.

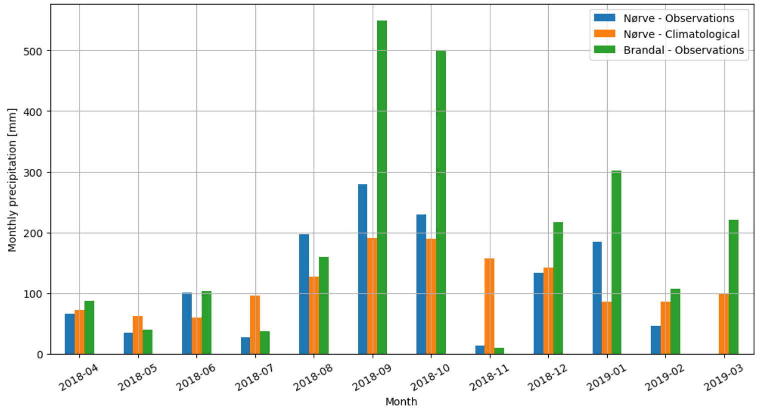


Figure 17. Monthly measured precipitation at Brandal (green), compared to the same period (blue) and a mean for 2009 - 2019 (orange) at the reference station Nørve in Ålesund.

Table 1: Overview of key parameters regarding the meteorological measurement sites, grouped by location. Boom direction is given as the true direction as seen from the mast, and can be used for all levels. An empty end date for the observation period implies that the observations are ongoing. Observed variables are wind speed (f) and direction (d), vertical wind speed (w), temperature (t), dew point (td), relative humidity (rh) and atmospheric pressure (prs).

Fjord	Mast	Mast height	Ground level	Coordinates (UTM 32 / WGS84 geographical)	Observation period	Sensor heights [m]	Boom dir.	Var.
Sula-fjorden	Kvitneset	100.5 m	6 m	6924741 N, 345142 E 62.421595° N, 6.00112° E	2016-11-24 -	92.5, 44.5, 71.5	72°	f, d, w
	Kvitneset temperature		6 m	6924741 N, 345142 E 62.421595° N, 6.00112° E		21.0. 44.0, 71.0, 92.0		t
	Kvitneset Klima		6 m	6924741 N, 345142 E 62.421595° N, 6.00112° E	2017-06-27 -	9.0		t, td, rh, prs
	Langeneset	97.0 m	6 m	6920740 N, 346520 E 62.386301° N, 6.031318° E	2017-04-26 -	27.0, 50.0, 75.0, 94.8	80°	f, d, w
	Trælbodneset	78.0 m	14 m	6925267 N, 348347 E 62.42763° N, 6.062626° E	2018-01-03 -	27.3, 48.3, 76.8	289°	f, d, w
	Trælbodneset temperature	78.0 m	14 m	62.42763° N, 6.062626° E		3.0, 30.0, 50.0, 78.0		t
	Kårsteinen	63 m	12 m	6922074 N, 351140 E 62.400201° N, 6.119176° E	2017-12-04 -	13.4, 40.0, 62.8	222°	f, d, w
	Brandal precipitation		27 m	6922033 N, 345589 E	2018-03-15 -	1.5		r
Hjørund-fjorden	Gjeveneset	30 m	3 m	6916898 N, 365563 E 62.359209° N, 6.402158° E	2018-03-14 -	18.5, 29.0	267°	f, d, w
Vartdals-fjorden	Rjåneset	72.0 m	8 m	6905511N, 342274 E 62.248022° N, 5.963142° E	2017-04-28 -	28.8, 51.4, 71.5	278°	f, d, w
Julsundet	Midsund	50m	24m	6957381 N, 394530 E 62.731663° N, 6.936432° E	2014-02-11 - 2019-03-26	31.9, 12.7, 50.3	73°	f, d, w
	Julbø	50 m	4 m	6957730 N, 396210 E 62.735273° N, 6.969062° E	2014-02-14 -	12.7, 31.9, 50.3	233°	f, d, w
	Nautneset	68 m	2 m	6957381 N, 394634 E 62.731693° N, 6.938466° E	2016-11-10 -	32.7, 52.3, 68.3	238°	f, d, w
Halsa-fjorden	Halsaneset	50 m	4 m	6995095 N, 456472 E 63.082697° N, 8.138198° E	2014-02-26 -	12.7, 31.9, 50.3	104°	f, d, w

	Åkvik	50 m	6 m	6995697 N, 458519 E 63.08834° N, 8.178568° E	2015-03-06 2020-05-08-	17.0, 31.9, 48.3	225°	f, d, w
	Åkvik2	100 m	6 m	6995697 N, 458519 E 63.08834° N, 8.178568° E	2020-05-09 -	48.3, 78.1, 97.2	225°	f, d, w

Table 2: Main statistics of wind data set at top sensor, including mean, median, maximum wind speed and 99th percentile of wind speed, the maximum gust (3 s), as well as the 99th percentile of the up/down vertical wind gust [ms^{-1}].

Fjord	Mast	Height [m]	Mean wind speed	Median wind speed	Maximum wind speed	99th perc. of wind speed	Max. gust	99th perc. vert. gust
Sulafjorden	Kvitneset	92.5	5.64	5.03	29.70	16.52	37.0	-13.4 / 8.6
	Langeneset	94.8	3.59	2.95	24.34	13.26	37.3	-13.6 / 7.4
	Trælbodneset	76.8	5.01	4.24	27.04	15.97	46.1	-9.2 / 7.1
	Kårsteinen	62.8	3.17	2.39	23.21	12.97	32.1	-8.6 / 6.3
Hjørundfjorden	Gjeveneset	29.0	5.85	4.83	23.55	17.82	43.6	-6.3 / 5.7
Vartdalsfjorden	Rjåneset	71.5	6.04	5.04	25.18	17.34	41.2	-6.8 / 6.3
Julsundet	Midsund	50.3	4.61	4.45	28.15	11.75	40.0	-7.4 / 6.2
	Julbø	50.3	5.47	5.15	26.74	14.14	39.6	-4.8 / 5.0
	Nautneset	68.3	4.80	4.59	28.46	12.83	41.9	-9.0 / 6.1
Halsafjorden	Halsaneset	50.3	4.30	3.91	23.87	12.62	35.1	-5.0 / 4.3
	Åkvik	48.3	3.80	3.03	23.00	12.94	34.4	-3.5 / 4.8