Characterization of Wind Channeling Around Longyearbyen, Svalbard

Karakterisering av vindkanalering runt Longyearbyen, Svalbard

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Abstract

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Due to climate change and arctic amplification, the avalanche activity is expected to increase at higher latitudes (Hall et al., 1994). The arctic settlement of Longyearbyen, Svalbard, situated inside the valley Longyeardalen, is yearly threatened by avalanche activity (Eckerstorfer & Christiansen, 2011a). The surrounding slopes are known to produce avalanche, and during the last century they have proven to be able to cause substantial damages and even fatalities (Hallerstig, 2010). Previous studies investigated magnitude and forcing of the avalanches, including a meteorological perspective (Eckerstorfer & Christiansen, 2011b). This allowed for the usage of forecasts from the weather model AROME-Arctic in order to have an avalanche bulletin.

The forecast for the area of Longyearbyen suffers from the location and the insufficient resolution of its source data. The data are obtained from an AWS located at the local airport, at the mouth of a relatively wide NW/SE oriented valley. Conversely, Longyeardalen is oriented NE/SW and is narrower. Because of the topography, channeling of winds is expected to produce difference weather conditions at the two sites, generating two distinct local weather conditions (Whiteman, 2000). If these different weather conditions are not taken into account, the weather model may provide forecasts that are not reliable for the area of Longyeardalen, hence resulting in biased avalanche bulletins.

In this work I compare the data from the airport, from Longyeardalen and from the plateau above in order to assess if relevant differences exist in some important meteorological parameters (temperature, wind speed and direction, precipitation) between these sites. The weather station at the airport is an official AWS while the data from the other two sites were obtained using portable weather stations deployed during a field campaign between March 1st and April 11th 2018. During this time, snow data from the slopes surrounding Longyeardalen were also obtained. These data have been used to look for correlations among the wind conditions in the valley and the depth of the snow, as it is known that snow transport is a major factor determining snow accumulation in the area (Jaedicke and Sandvik, 2002; Hestnes, 2000).

Temperature and precipitation have been found to be consistent among the two investigated valleys, while wind parameters differed significantly. Wind speed in Longyeardalen is on average overestimated by 3 m/s if only the data from the airport are used while the direction data are uncorrelated. This is due to the different circulations that occur at the two sites. Adventdalen is mostly influenced by southeasterly winds that are forcibly channeled or induced by the synoptic circulation, while in the smaller Longyeardalen southerly winds prevail due a thermal circulation induced by the presence of two glaciers on the top part of the valley. Snow depth is altered by the wind transport but it was not possible to find any correlation due to the low resolution of the snow depth data.

Keywords: Longyeardalen, wind channeling, snow transport

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Data som används av denna modell förväntas på något sätt vara fel eftersom skillnader i det lokala vädret uppstår på grund av områdets topografi. Det är känt att berg och dalar i allmänhet kan hindra vind från att strömma in i en viss riktning eller tvärtom tvinga den att göra det. Denna process kallas vindkanaliserande och det sannolikt att den har några effekter även i Longyearbyen och dess dal, Longyeardalen. Denna dal är orienterad på ett sätt som gör det lättare att interagera med vindar från sydväst, medan dalen där flygplatsen ligger sannolikt kommer att reagera bättre på sydostliga flöden, vilket också är den rådande vinden i regionen. Det förväntas därför att vindhastigheten och vindriktningen i Longyeardalen inte kommer att vara densamma som vid flygplatsen, trots det korta avståndet mellan de två platserna. Detta kan också ha effekt på temperatur och nederbörd. Om skillnaderna mellan de två platserna är för stora, är prognoserna från flygplatsen knappast till någon hjälp för att förstå lavinrisk i Longyearbyen.


Jag fick reda på att båda dalarna påverkas starkt av kanaliserande fenomen. På flygplatsen är vindar starkare och har i allmänhet en sydostlig riktning, även om vinden högt upp inte har exakt denna riktning. I detta fallet dirigerar dalen vinden så att de strömmar parallellt med den. Longyeardalen har vanligtvis sydvästlig vind, trots att sådana vindar inte uppträder så ofta högt uppe. Dessa vindar orsakas av temperaturskillnaden mellan två glaciärer längst inne i dalen och det relativt varma vatten i fjorden vid öppningen av dalen. Denna skillnad gör att den kalla luften sjunker mot dalen och genererar vind. I allmänhet var det inte möjligt att bestämma om vinddata kan användas för att förstå hur mycket snö som transporteras på grund av komplexiteten hos de mätningar som behövs för att göra det.

Nyckelord: Longyeardalen, vindkanalering, snötransport

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1 Introduction

Snow avalanches represent a major threat for the high Arctic settlement of Longyearbyen and the surrounding area, which has a long history of avalanche-related damages and casualties (Hallerstig, 2010).

After a slushflow caused 3 casualties and destroyed the local hospital in 1953, precautions have been taken in order to decrease the risk related to natural avalanches (Balstad, 1956). Despite these initial precautions, large areas are still unprotected. In particular, in the residential area of Lia the life toll has still been high in recent years (with 2 victims on December 19th 2015) and the damages to the infrastructure have been significant (several residential building destroyed in the 2015 avalanche and during another event in February 2017) (Hancock, submitted). Furthermore, avalanche risk leads annually to mass evacuations of part of the settlement (Lia and Nybyen) causing relative discomfort (e.g. NRK, 2018; Sysselmannen, 2017; UNIS, 2016, The Local, 2016; Stange, 2015). The recent events resulted in an increase in the efforts to improve forecasts using both traditional methods and modern remote sensing instruments (Hancock, submitted), while relatively little has yet been addressed to physically protect (e.g. with snow fences) parts of the settlement, even though some precautions are scheduled for the near future.

Despite its central role in the high Arctic from a societal and logistical point of view, relatively little meteorological and nivological research has specifically addressed the valley Longyeardalen, where Longyearbyen lies. Conversely, more is known about the broader region Nordenskiöldland and for the valley system that includes Longyeardalen (Christiansen et al., 2013; Hallerstig, 2010; Eckerstorfer et al., 2008), at least if compared to the scarce amount of literature available for such latitudes (Eckerstorfer & Christiansen, 2011a).

In the area of Longyeardalen it has been observed that the topography modifies the general weather circulation so that the avalanche activity is influenced by local weather processes (Eckerstorfer & Christiansen, 2011b). Despite the clear influence of the topography on speed and direction of the wind (Christiansen et al., 2013; Eckerstorfer & Christiansen, 2011b; Hallerstig, 2010) literature lacks an extensive study that covers specifically the wind conditions in Longyeardalen. Understanding this variable is particularly relevant as it has been listed as the second most important meteorological parameter for avalanche forecasts in the area (Eckerstorfer & Christiansen, 2011a) and because of its influence on snowdrift. Snowdrift has been found to be significant in Longyearbyen (Hestnes, 2000) and constitutes a major factor in the contribution to avalanche risk because of its capacity of building slabs and cornices and for the lack of tall vegetation (Hancock, 2016; Vogel et al., 2012; Eckerstorfer et al., 2008). The scarce precipitation in the valley, modeled by Humlum (2002) contributes to the formation of thin weak layers that
enhance the possibility of avalanching (Eckerstorfer et al., 2008) and constitutes the most important meteorological variable in terms of avalanche forecasting in Longyeardalen (Eckerstorfer & Christiansen, 2011a). In turn, temperature seems to not have a primary relevance in causing avalanches in the study area (Eckerstorfer & Christiansen, 2011a).

As for now, the only forecasting tool for snow avalanches in Longyeardalen is a product derived from AROME-Arctic (Müller et al., 2017), a tailor-made version of the well documented AROME model used for weather forecasting at mid latitudes (Seity et al., 2011). The main issue with AROME-Arctic is that it cannot capture the topography and the local weather in the valley since its resolution is too coarse (2.5 x 2.5 km grid). Indeed, the effort to protect effectively from snow avalanches the town of Longyearbyen needs to include several elements. Unless (or until) an extensive system of snow fences, costing 100 million NOKS (NRK, 2018), gets built, there is a urgent need for better local avalanche forecasts. This necessarily involves a better knowledge of the conditions of the snowpack and its evolution in the targeted areas, which in turn is heavily influenced by the local weather (Eckerstorfer & Christiansen, 2011b).

With this work I will try to assess if the local weather conditions in and above Longyeardalen are similar to what is reported by the AWS at Svalbard airport. The airport AWS is the station used by the Norwegian meteorological institute as a primary source to represent this area of Svalbard within AROME Arctic. Furthermore, I will investigate what is the impact of the local weather on the snowpack, if any, with a focus on the areas that are potential sources of snow avalanches.

To investigate the local weather, I will use the data obtained by a set of instruments that were deployed in several locations within Longyeardalen during a field campaign I held between March 1st and April 10th 2018. This dataset will be compared with the official record from the station at the airport. In order to assess if there is any impact from the local weather on the snowpack, I will look for correlations between the data from the weather stations and the measurements from three different snow stations located on the sides of the valley.

In the following, Chapter 2 will give an overview of the study area and will provide the theoretical background for meteorology and snow science, Chapter 3 will describe the instrumental setting and the methods, Chapter 4 will display the results, which I will analyze in Chapter 5, while Chapter 6 will conclude this work.
2 Background

2.1 Area

The Svalbard archipelago is situated in the high Arctic and extends for roughly 63000 km$^2$ between 74 to 81°N and 10 to 35°E (Figure 1). The area is characterized by mountains with a plateau form at around 500 m a.s.l., but peaks up to 1000 m are also present. The mountains are divided by U-shaped valleys carved by glaciers, which cover an important portion (60%) of the island but not of the study area. There is no tall vegetation and most of the surface is covered by sedimentary rocks of medium size. Underneath, permafrost extends from 100 to 500 m underground (Humlum et al., 2003).

![Figure 1](image.png)

Figure 1. Position of Svalbard, located in the high Arctic and highlighted by a red circle.

The climate of Svalbard has been defined as "high Arctic maritime snow climate". This means that the snowpack is generally thin, hard and dense, commonly with weak layers that tend to fail (specially during the transition to midnight sun in spring) as a consequence of the action of the wind and precipitation (Eckerstorfer & Christiansen, 2011a). The latter is rather scarce (190 mm/yr in the study area) (Humlum, 2002; Førland et al., 1997) even though recently, due to increased cyclonic activity, the amount of rain and of ROS (rain on snow) events has increased (Rennert et al., 2009). In fact, in the Arctic cyclones have an important role in terms of heat transport and precipitation...
(Bengtsson et al., 2006). This is particularly true during autumn and winter, when short lasting strong cyclones originating in the North Atlantic are pushed towards higher latitudes by the North Atlantic Oscillation (NAO) (Zhang et al., 2004). A 40% reduction in the summer Arctic sea ice extent has occurred in the last 40 years (Serreze et al., 2008) and has led to larger areas where heat can be transferred to the atmosphere from the underlying ocean, with the result of a warmer atmosphere during autumn and winter. This constitutes a contributory factor to the Arctic amplification that is expected to result in a northward shift of the regions that have the highest baroclinic instability, with the overall effect that storm tracks will be reallocated polewards (Hall et al., 1994) and the subsequent increase in precipitation for regions like Svalbard. Furthermore, it is documented that the precipitation in Svalbard increased by 2% every ten years in the last century (Førland et al., 2009).

Despite the low amount of precipitation at sea level, differences in altitude result in a significant gradient in the vertical distribution of rain because of the complex topography of this mountainous area. The winds, with their mean direction from SSE, are noteworthy and play an important role in the redistribution of snow (Hancock, 2016; Eckerstorfer et al., 2008). The temperature ranges from a monthly average of -15.2°C (February) to 6.2°C (June) (Eckersorfer et al., 2008), but important rising in these mean values have been observed in the last century, with a rate of 0.22°C per decade (Førland et al., 2009). It is remarkable to notice that these temperatures are warmer than what is usually found at such latitudes due to the year-round influence from the warm West Spitsbergen current (Walczowski & Piechura, 2011).

The area has been investigated in the transition period between the end of the polar night (which occurred on February 16th) to the midnight sun (which began on April 19th) (Time and date, 2018), passing through the Solfest (8 March), when Longyeardalen gets its first direct radiation from the sun (Lokalstyre, 2018b). Hence, the terms of the surface energy budget are expected to change dramatically, with increasing amounts of incoming shortwave radiation.

The biggest settlement on Spitsbergen (the main island of Svalbard archipelago) is Longyearbyen, which has some 2200 registered inhabitants (Statistisk sentralbyrå, 2017) as well as several hundreds of university students and tourists. The town is located, as all the other settlements of Svalbard, on the western coast of Spitsbergen (Toposvalbard, 2018). The west coast is characterized by big fjords oriented latitudinally. The biggest of these West facing fjords is Isfjorden, and Longyearbyen is located inside a minor fjord inside it, Adventfjorden. The town extends on a North-East/South-West direction with an area of roughly 4 km², confined in the valley Longyeardalen. The valley is bounded by the 514 m high mountain Sarkofagen neighbored by the glaciers Longyeardalen and Longyearbreen (South), by the 450 m high Sverdruphamaren plateau.
(West), by the fjord Adventfjorden (North) and the 450 m high Gruvefjellet plateau and by the 424 m high mountain Sukkertoppen (East), as displayed in Figure 2. The latter are divided by a 1200 m long gully called Vannledningsdalen (Toposvalbard, 2018).

Because of its position in the valley and for the nature of the slopes in the surroundings, several parts of the town are endangered by snow avalanches. Longyeardalen is mostly subject to loose snow avalanches (37%, due to the steep west valley side), cornice falls (33%) and slabs (16%), that despite the smaller occurrence happen to be close to residential areas (Eckerstorfer et al., 2008). No clear time distribution is known for dry slab avalanches, while loose snow avalanches are more common after the end of the polar night (Eckerstorfer et al., 2008), as well as the cornices falls, that are triggered by the temperature increase (Vogel et al., 2012) and the strong winds (Eckerstorfer et al., 2008).

Figure 2. Topographical map of the area surrounding Longyeardalen. Darker colors represent higher altitudes, contour lines are displayed in black every 100 m. The red circle represents the main urban area. In the upper right corner, position of the area in relation to Spitsbergen. North is upwards (Adapted from Toposvalbard, 2018).
Some avalanche safety measures are scheduled to take place in the near future. In particular, parts of Lia will soon be protected with a snow fence (NRK, 2018) while the student housing, that represents most of the endangered infrastructure in Nybyen, is likely to be moved away by 2019 (Lokalstyre, 2017). Other buildings in Nybyen (two hotels and a museum) will stay in place, as well as the endangered road that leads to the restaurant Huset. Details on these areas are displayed in Table 1 (Lokalstyre, 2018a).

Table 1. Areas of Longyearbyen endangered by snow avalanches.

<table>
<thead>
<tr>
<th>Area</th>
<th>Detail</th>
<th>Avalanche threat source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nybyen</td>
<td>Student housing and hotels</td>
<td>Gruvefjellet</td>
</tr>
<tr>
<td>Veg 100</td>
<td>Road that leads to Nybyen, eastern side of Longyeardalen</td>
<td>Gruvefjellet</td>
</tr>
<tr>
<td>Huset</td>
<td>Restaurant</td>
<td>Sverdruphamaren</td>
</tr>
<tr>
<td>Veg 300</td>
<td>Road that leads to Huset, western side of Longyeardalen</td>
<td>Sverdruphamaren</td>
</tr>
<tr>
<td>Skjeringa</td>
<td>Church, Sysselmannen (Governor building), other facilities</td>
<td>Sverdruphamaren</td>
</tr>
<tr>
<td>Haugen</td>
<td>Residential area</td>
<td>Vannledningsdalen</td>
</tr>
<tr>
<td>Lia</td>
<td>Residential area</td>
<td>Sukkertoppen</td>
</tr>
</tbody>
</table>

2.2 Meteorology

2.2.1 Atmospheric boundary layer and its stability

Stull (2012) defines the atmospheric boundary layer (ABL) as the part of the troposphere that changes in relation to surface forcing on a short timescale. Its daily evolution is extremely variable: during the day it gets heated by turbulent heat fluxes from the ground, while ground cooling at night produces temperature inversions (Foken, 2008).

To better understand the behavior of the boundary layer it is worth to introduce the potential temperature \( \theta \), which is the temperature of a dry air parcel ideally moved adiabatically to a pressure level of 1000 hPa. It can be calculated using

\[
\theta = T \left( \frac{1000}{p} \right)^{R/c_p} \tag{2.1}
\]

where \( T \) and \( P \) are temperature and pressure measured at the particle height, \( R \) is the gas constant for air, and \( c_p \) is the specific heat at constant pressure (Kaimal & Finnigan, 1994). Using the hydrostatic equilibrium and assuming unsaturated conditions it is possible to approximate equation 2.1 with

\[
\theta = T + 0.0098z \tag{2.2}
\]
where $T$ is the temperature and $z$ is height of the instrument above sea level (Kaimal & Finnigan, 1994).

It is possible to use the potential temperature to predict the behavior of an air parcel that gets lifted in unsaturated conditions. In an environment where potential temperature decreases with height, as in a typical daytime boundary layer, a particle that gets adiabatically lifted will be warmer than the surroundings, hence it will continue rising. The opposite applies if the particle is displaced downwards in such an environment, as it will be colder than the surrounding particles and hence it will keep descending. In this case the boundary layer is unstable (Holton & Hakim, 2012). In the case of temperature inversions, occurring generally in the nighttime boundary layer, the potential temperature increases with height. This means that if a parcel is displaced upwards, it will be colder than the surrounding atmosphere and will therefore tend to go back to its initial equilibrium state. The same applies if the particle tries to descend: in that case it will be warmer than the surroundings and it will be forced to ascend to its starting position. The boundary layer is then defined to be stable (Holton & Hakim, 2012). As a third case, if after a vertical movement the particle is in a new equilibrium state, the boundary layer is neutral (Holton & Hakim, 2012).

One of the most common ways to quantify the stability of the ABL is given by the Richardson number $Ri$, which uses the temperature and speed gradients and is defined as

$$Ri = \frac{g}{\theta_0} \left( \frac{\partial \theta}{\partial z} \right)^2$$

where $g$ is the gravity acceleration, $\theta_0$ is a reference temperature for the layer, and $\overline{u}$ is the mean wind speed (Kaimal & Finnigan, 1994). Negative values of $Ri$ imply an unstable stratification while positive values are a sign of stability. Neutral conditions are given in the case of values close to zero.

### 2.2.2 Monin-Obukhov similarity theory

Wind profiles, as well as temperature profiles, seem to present similar shapes if scaled properly. The scaling approach, introduced by Monin and Obukhov (1954), is called similarity theory (MOST). MOST is based on a series of assumptions in order to take care only of what is locally generated. These assumptions are:

1. fluxes are constant with height
2. homogenous horizontal conditions
3. quasi stationary conditions
4. molecular exchanges of momentum and head and negligible if compared to turbulent exchanges
rotational effects can be ignored

The overall result is that the theory is valid only within the surface layer, which represents the lowest 10% of the ABL. The theory allows for the comparison of two surface layers starting from 4 key variables: height $z$ above the ground, buoyancy parameter $\frac{g}{\rho}$, kinematic surface stress $\tau_0 = \overline{u' \omega'}$, and kinematic heat flux $\overline{\omega' \theta'}$. In fact, with dimensional analysis, these variables are used to obtain 4 scaling parameters: friction velocity, temperature, Obukhov length and height above ground.

Friction velocity is a velocity scale constructed from the shear wind stress and represents how much horizontal movement is moved vertically. It is defined (Kaimal & Finnigan, 1994) as

\[ u_* = \sqrt{\frac{-\tau_0}{\rho}} \]  

(2.4)

Temperature is a temperature scale obtained from the kinematic heat flux and the friction velocity. It is defined (Kaimal & Finnigan, 1994) as

\[ T_* = -\frac{\overline{\omega' \theta'}}{u_*} \]  

(2.5)

Stability parameter $\zeta$ gives a measure of the stability of the boundary layer and is defined (Kaimal & Finnigan, 1994) as

\[ \zeta = \frac{z}{L} \]  

(2.6)

If this parameter is negative, the ABL is unstable, while positive values mean stability. In the case of values close to zero, neutral conditions exist. The parameter $L$ used in eq. 3.5 is the Obukhov length, which is a length scale gained using the two previous scaling variables, the buoyancy parameter and the Von Karman constant. It is defined (Kaimal & Finnigan, 1994) as

\[ L = -\frac{u_*^3 \theta}{k \overline{\omega' \theta'}} \]  

(2.7)

where negative sign has been introduced in order to give $\zeta$ the same sign as the Richardson number (Kaimal & Finnigan, 1994) and the Von Karman constant has a value of 0.40 obtained from field results (Högström, 1996).

2.2.3 K-Theory

To obtain good data about the kinematic momentum transfer $\overline{u' \omega'}$ and the kinematic flux of heat $\overline{\omega' \theta'}$ it would be necessary to use a sonic anemometer and use some turbulence theory. The K-theory allows to usage of vertical changes in the average values of $\theta$ and $\overline{u}$, which are easier to obtain, in order to calculate these variables using the formulas.
where $K_m$ and $K_h$ are the exchange coefficients for momentum and heat respectively. It is assumed that close to the ground these constants have the same value (Panofsky & Dutton, 1984).

2.2.4 Wind and temperature profiles

Dimensionless parameters for momentum and heat can then be introduced starting from the scaling variables. These parameters are defined (Kaimal & Finnigan, 1994) as

\[
\begin{align*}
\phi_m &= \frac{k z \partial \bar{u}}{u_* \partial z} \\
\phi_h &= \frac{k z \partial \bar{\theta}}{T_* \partial z}
\end{align*}
\]

These equations are valid given the assumption of neutral conditions, which is not the case for many real cases. Several field campaigns have been carried out in order to expand this representation to take into account stable and unstable conditions. Some relevant results were obtained by Businger et al. (1971) using the data from the Kansas Field Program (Haugen et al., 1971). Their equations, as well as other studies, were merged by Högström (1996) in his review. He presented the profiles that are now commonly accepted, as well as a fixed value of 0.40 for the Von Karman constant. The profiles introduced for the unstable case were

\[
\begin{align*}
\phi_m &= (1 - 19\zeta)^{-1/4} \\
\phi_h &= 0.95(1 - 11.6\zeta)^{-1/2}
\end{align*}
\]

In the case of stable conditions and $0 \leq \zeta \leq 0.5$, Högström (1996) suggested

\[
\begin{align*}
\phi_m &= 1 + 5.3\zeta \\
\phi_h &= 1 + 8.0\zeta
\end{align*}
\]

but recent studies (Andreas, 2002) have been able to extend the representation to all the stable cases, if the formula that get used is

\[
\phi_m = \phi_h = 1 + 0.7\zeta + 0.75\zeta(6 - 0.35\zeta)^{-0.35\zeta}
\]

2.2.5 Wind in valleys

Topography is an important factor to consider in mountainous areas, as it can redirect large scale winds (terrain forced flows) or be one of the factors that induces a purely local circulation in valleys (Whiteman, 2000).
Typically, terrain forced flows occur when the winds aloft are strong or during unstable conditions, resulting in a downward momentum transport. In this case, the stability and the speed of the air that approaches the mountain range and the topographic characteristics of the terrain regulate the actions of the air mass. Local winds are instead caused by weak winds aloft or by stable conditions, so that the downward momentum transfer is minimal. In this case the driving force of the wind is the radiative heating or cooling of the valley and its slopes (Whiteman, 2000). Literature reports three different terrain forced flows and one thermal forced flow (Whiteman & Doran, 1993).

**Downward momentum transport** of horizontal momentum can occur due to vertical turbulent mixing or gravity waves. In this case the wind conditions in the valley are similar to the geostrophic flow, with a left turn of about 25° due to the friction with the terrain. This phenomenon is typical for wide flat-bottomed valleys with low sidewalls when the ABL is unstable or neutral (Whiteman & Doran, 1993).

**Forced channeling** of the ambient winds above the valley can occur in valleys due to their sidewalls. Depending on the speed and the direction of the winds aloft, winds in the valley are forced to blow up or down-valley (Whiteman & Doran, 1993). This mechanism is mostly observed in short deep valleys (Whiteman, 2000).

**Pressure driven channeling** is caused by geostrophic pressure gradients caused by synoptic highs and lows. Their position and their relative movement with respect to the valley induce winds that change gradually, with the maximum magnitudes when the pressure gradient is oriented along the valley (Whiteman, 2000; Whiteman & Doran, 1993).

**Thermal forcing** is caused by pressure gradients present along the valley, hence they don’t depend on the wind conditions above it. The pressure gradients are hydrostatically caused by temperature differences in long and deep valleys. At mid latitudes, the result of these gradients is the onset of a diurnal cycle, with up-valley winds during daytime and down-valley winds during nighttime (Whiteman & Doran, 1993). At higher latitudes the diurnal variations are smaller and the boundary layer is typically stable, with down-valley winds prevailing most of the time (Serreze & Barry, 2014). For this phenomenon to occur, weak winds aloft or deep strong inversions are needed (Whiteman, 2000), with the latter being often the case in Arctic wintertime (Serreze & Barry, 2014).

### 2.3 Snow science

#### 2.3.1 Snow formation in the atmosphere

Snow formation occurs in atmospheric clouds in a process analogous to the formation of rain. Cloud condensation nuclei, which are particles with a typical scale of one micron or less, grow by
condensation of water molecules in a water vapor saturated environment (Rogers & Yau, 1976). These particles are generally made of dust, but salt is also important in areas where the ocean can provide amounts of this chemical compound.

If the air temperature at the saturation point is below 0°C, water droplets become supercooled. In this case, snow can be formed by the droplets interacting with freezing nuclei, which are small ice crystals with a particular molecular structure that supports freezing (McClung & Schaerer, 2006; Rogers & Yau, 1976). Several chemical compounds can act as freezing nuclei if the air temperature is sufficiently low. Because of that, the number of available nuclei increases with decreasing temperatures (McClung & Schaerer, 2006). Eventually, at temperatures below -40°C, the formation of ice crystals will occur without any nucleus in a process called homogeneous freezing (Rogers & Yau, 1976).

The ice crystals formed by these mechanisms are still small and rely on two different growth processes to increase their size. The first mechanism is driven by pressure: water vapor is diffused from supercooled water droplets to ice crystals as the vapor pressure is slightly higher on the droplet than on the crystal. The second way to increase the size of the crystal is riming and is related to motion (McClung & Schaerer, 2006). When the crystal is large enough, it falls through the cloud, hitting and collecting other ice crystals and forming snowflakes. When supercooled water droplets are also involved, they can freeze on the crystal itself and eventually form hail or graupel. (Rogers & Yau, 1976).

The way the droplets are added to the ice crystal, and the residence time of the crystal within the cloud, influences its structure (McClung & Schaerer, 2006).

2.3.2 Snow deposition on the ground

Snow falls on the ground in the form of solid precipitation. Several factors influence the precipitation and hence the amount of snow that manages to reach to ground.

First of all, warmer temperatures in the atmosphere underneath the cloud can melt the snowflake and transform it to liquid precipitation (Rogers & Yau, 1976). Also the topography can have an impact, as elevated terrain experiences lower temperatures than the sea level because of the temperature decrease due to the lapse rate. This might lead to cases in which it is snowy only above a certain altitude.

Wind plays an important role in snow deposition because of its ability to transport snow between two locations, hence changing the spatial distribution of the snow. The impact of the snowdrift due to wind depends mostly on wind speed, the amount of uniform terrain upwind the location (fetch) and the characteristics of the snow surface. Depending on the strength of the wind, three different
processes may occur on previously deposited snow: creep, saltation and turbulent suspension (McClung & Schaerer, 2006). Creep plays a minor role in terms of mass transport and consists in the rolling of particles that cannot be lifted by the wind. Saltation occurs when the force of the wind exceeds the resistance caused by the friction induced on the snow particle by the surrounding terrain, resulting in a semi parabolic trajectory that may be repeated several times or trigger the motion of other particles (Lehning et al., 2008). This process is important in terms of snow transport, as it can account for more than 50% of the mass transported when the wind is less than 10 m/s at 10 m height (Pomeroy & Gray, 1990). When more energy is available due to higher wind speeds, turbulence can suspend snow particles and transport them without further interaction with the ground. With wind speeds above 17 m/s this process can account for 90% of the snow transport (Pomeroy & Male, 1992). It is noteworthy that turbulent suspension also leads to losses in the amount of snow as sublimation occurs when the particles are lifted higher up (Pomeroy, 1991). Despite some contrasting results in the research to account for the wind impact, it is well understood that snow transport is proportional to the cube/fourth power of the wind speed and also it increases with less consolidated snow or with increasing fetch (Tabler et al., 1990). This latter term hints that the terrain plays an important role also after the snow has deposited on the ground. In fact, while the fetch is significant for wind transport, mechanical transport can occur even without wind on slopes due to gravity overcoming the snow's cohesion with the terrain. Furthermore, the type of terrain influences the effectiveness of such transport, as rough terrain or vegetation can significantly increase the friction and promote some deposition (Armstrong & Brun, 2008). Also, terrain traps, hollows, and lee zones are favored areas for snow deposition (McClung & Schaerer, 2006). At large scales, terrain features like valleys or woodlands can decouple the surface from the boundary layer, eventually resulting in the accumulation of snow downwind (Armstrong & Brun, 2008).

2.3.3 Snow metamorphism
As soon as snow crystals touch the ground, their structure starts to change in a process called metamorphism. Metamorphism of the snow on the ground occurs in part due to the decrease in the percentage of supersaturation relative to that in the atmosphere. In fact, on the ground the supersaturation is on the order of 1% and it is not enough to maintain the same conditions that were provided by the highly supersaturated atmosphere (McClung & Schaerer, 2006).

As for the crystal formation in the previous section, the vapor pressure gradient has to be taken into account to understand why snow crystals modify their shape. When a difference in vapor pressure is experienced by a crystal, water molecules leave or get deposited on the crystal until an
equilibrium status is reached between the particle and the surrounding environment. Vapor pressure is influenced by the radius of curvature and by the temperature and temperature gradient as well as the pore space between crystals (McClung & Schaeerer, 2006; Armstrong and Brun, 2008). In fact, vapor pressure is higher on sharp elements, meaning that elements with high surface-to-volume ratio, as the newly fallen snow crystals, are prone to sublimate water molecules in order to obtain a more rounded shape with a lower vapor pressure. By releasing water particles crystals become smaller, thus this type of metamorphism is called destructive (McClung & Schaeerer, 2006; Armstrong & Brun, 2008).

When the radius of curvature is larger than $10^{-2}$ mm, temperature and pore-space size begin to influence vapor pressure more than the crystals shape. Temperature gradients in the snowpack are induced by the fact that the snowpack extends between the ground, which has typically temperatures around 0°C due to geothermal heating, and the overlying atmosphere (McClung & Schaeerer, 2006). Temperature gradient has an impact on the vapor pressure because the vapor diffuses from warmer to colder surfaces via the air that occupies the pore-space (Armstrong & Brun, 2008).

As a general rule, large temperature gradients, together with larger pore-spaces, result in elevated growth rates that result in faceted crystals. Conversely, small gradients and high crystal density result in low growth rates, which produce rounded crystals. High temperatures in the snowpack typically imply lower temperature gradients (as the air at the boundary is also relatively warm), so the conditions mentioned above might not occur as a whole. The temperature gradient has an overall more significant impact than the temperature itself, and it has been established that a temperature gradient of 10°C/m is significant to discriminate between low and high growing rates. The growing phase of the crystals is called constructive metamorphism (McClung & Schaeerer, 2006).

2.3.4 Snow avalanches

Snow avalanches occur on sloping terrain and a first classification can be done using the triggering factor: natural avalanches are caused by environmental factors as snow cornices breaking and snow melting or depositing over the existing snowpack, while artificial ones occurs because of the interaction of snow with people or wildlife. Although the latter type of avalanche is the one which causes the most casualties among skiers and mountaineers, natural avalanches are the ones which endanger settlements (Schweizer et al., 2003).

According to their structure, avalanches can also be divided into loose-snow avalanches and slab avalanches. The first type is characterized by a triangular pattern, as the avalanche starts from the
failure of the surface snow at a specific point on the slope and spreads laterally as it moves
downslope. The second type involves a failure that propagates with a fracture inside a weak layer of
the snowpack, resulting in the movement of the overlying cohesive snow slab (McClung &
Schaerer, 2006).

Terrain has a significant impact in the formation of avalanches, as first of all there is the need for
a sloping surface. Avalanche prone terrain has been identified as slopes between 25° to 55°, even
though it is commonly accepted that the most dangerous areas are between 30° to 45°, with a peak
at 40°. Despite the increased chance of snow avalanches with increasing inclination, it is possible to
trigger avalanches from less steep slopes with a fracture that propagates upwards up to areas where
the tilt exceeds 25°. Also, the regular loose snow avalanching process that usually prevents slab
formation on slopes over 55° might not be sufficient to prevent avalanches on the steepest slopes
(McClung & Schaerer, 2006).

Temperature and temperature gradient influence properties like hardness, toughness and strength
of the snow, as well as having an impact on snow metamorphism. It has been reported that for the
vast majority of slab avalanches the recorded temperature is above -10°C, with an average value
around -5°C (McClung & Schaerer, 2006).

Finally, snow depth should be taken into account, as it is has been shown that the average depth of
the snowpack in an area prone to slab avalanches is around 0.6 m, even though the whole range
between 0.1 m and 1 m is of primary concern (McClung & Schaerer, 2006; Schweizer et al., 2003).
3 Instruments and methods

3.1 Instrumental setup

The instrumental setup includes various instruments scattered on sites allover Longyeardalen and the slopes surrounding it (Figure 3).

![Image 3: Position of the meteorological and nivological setup in the area of Longyeardalen. The airport station is located 5 km NE the study area. North is towards the top of the figure.](image)

3.1.1 Meteorological setup

A HOBO U30 weather station from Onset (hereafter "Hobo") was deployed in Longyeardalen at 87 m a.s.l., between "Sverdruphamaren" and "Gruvefjellet" (Figure 4). It was deployed on February 28th and it measured temperature and relative humidity at 1.85 m and 3.27 m with two S-THB-M002 sensors. The station also measured wind speed at the same heights with two S-WSB-M003 sensors and the wind direction at 3.27 m with a S-WDA-M003 sensor. Finally, pressure was sampled at 90 cm with a S-BPB-CM050 sensor. These variables were measured with a sampling rate of 10 seconds and logged with 10 minutes averages. In addition to that, a TinyTag 2 Plus TGP-4020 with a thermistor was placed on the ground in order to catch the surface temperature.
An automatic weather station (hereafter "Gruvefjellet") belonging to UNIS is located on the plateau Gruvefjellet at 464 m A.S.L. Since December 2006, it has recorded wind speed and direction at 3 m a.g.l., temperature and humidity at 10 cm, 1 m and 3 m a.g.l. and temperature at 1, 2, 3, 4 and 5 m underground. The wind is measured with a Young 05103 combined instrument while for temperature is used a set of PT1000 sensors. Data is stored with 1 h averages in CR 1000 dataloggers from Campbell (Christiansen et al, 2013).

The official records from the area are provided with 1 h resolution from the MET.no weather station at Svalbard airport. The station is located at 28 m a.s.l. in a flat area between the fjord Adventfjorden and a north-east facing mountain.

Figure 4: The Hobo station in Longyeardalen. On the background, the mountain Sarkofagen (left) and the plateau Sverdruphamaren (right).

Four other smaller stations were set up in order to monitor temperature and wind. A station called "Lia 200" was established on the path to Sukkertoppen on February 24th. This station recorded temperature at 65 and 165 cm a.g.l., wind at 75 cm a.g.l. and snow temperature at ground level in 10 minutes intervals. The station consisted of a WindLog from RainWise, a TinyTag 2 Plus
TGP-4520 from Gemini Data Loggers with two temperature sensors and a TinyTag 2 Plus TGP-4020 with a thermistor. The station was located at 157 m a.s.l. and it was positioned on a North facing slope. A station called "Hallen", consisting of a TinyTag 2 Plus TGP-4520 and a TinyTag 2 Plus TGP-4020, was established in the valley of Longyeardalen. The station was established on February 25th at 61 m a.s.l. in an open field between the river and the public gym Svalbardhallen. Two stations have been placed on a north-east facing slope in a 1200 m long gully (Vannledningsdalen) oriented south-east to north-west that divides Gruvefjellet from Sukkertoppen. The bottom station, "Vann 100", was established on February 25th at a height of 122 m a.s.l. and it had the same setup as "Lia 200". The top station, "Vann 200", was established on March 4th at a height of 230 m a.s.l. and it consisted of a TinyTag 2 Plus TGP-4505 and a TinyTag 2 Plus TGP-4020. The TinyTag 4505 had only one temperature sensor, at 160 cm, but it also measured humidity. The specifics of all the above-mentioned instruments are displayed in Table 2.

Table 2. List of the used sensors and their specifics.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Output</th>
<th>Range</th>
<th>Resolution</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>TGP-4020</td>
<td>Temperature</td>
<td>-40 to 125°C</td>
<td>0.02°C</td>
<td>0.60 to 0.35°C in the range -40 to 0°C.</td>
</tr>
<tr>
<td>TGP-4520</td>
<td>Temperature</td>
<td>-40 to 125°C</td>
<td>0.02°C</td>
<td>0.60 to 0.35°C in the range -40 to 0°C.</td>
</tr>
<tr>
<td>TGP-4505</td>
<td>Temperature</td>
<td>-25 to 85°C</td>
<td>0.01°C</td>
<td>0.50 to 0.35°C in the range -25 to 0°C.</td>
</tr>
<tr>
<td>TGP-4505</td>
<td>Relative humidity</td>
<td>0 to 100% RH at -25 to 85°C</td>
<td>0.3% RH</td>
<td>+/- 3.0% RH at 25°C</td>
</tr>
<tr>
<td>WindLog</td>
<td>Wind speed</td>
<td>0 to 67 m/s (threshold: 0.45 m/s)</td>
<td>0.1 m/s</td>
<td>+/- 2%</td>
</tr>
<tr>
<td>WindLog</td>
<td>Wind direction</td>
<td>360 degree (threshold: 0.9 m/s at 10 degree deflection)</td>
<td>22.5 degree, averaged</td>
<td>+/- 22.5 degrees</td>
</tr>
<tr>
<td>S-THB-M002</td>
<td>Temperature</td>
<td>-40 to 75°C</td>
<td>0.02°C at 25°C</td>
<td>+/- 0.21°C from 0 to 50°C</td>
</tr>
<tr>
<td>S-THB-M002</td>
<td>Relative humidity</td>
<td>0 to 100% RH at -40 to 75°C</td>
<td>0.1% RH</td>
<td>+/- 2.5% from 10 to 90% RH (typical) with a maximum of +/- 3.5% at 25°C.</td>
</tr>
</tbody>
</table>
### 3.1.2 Nivological setup

For the snow part, three stations were deployed by the Arctic Geology department of UNIS in December 2017. These stations record snow depth (with an acoustic snow sensor), air temperature and relative humidity at 2 m height and snow temperature at 0/50/100 cm height from the ground. All these instruments are from Campbell scientific and record on CR800 loggers. Data is recorded every 10 minutes. Station "Sverdruphamaren" is located on a plateau (Svedrduphamaren) at the western edge of Longyeardalen at 450 m a.s.l. on an east facing slope. Station "Nybyen" is located opposite to Sverdruphamaren, on a west facing slope below the edge of a plateau (Gruvefjellet) at 360 m a.s.l.. Station "Lia 100" is located at 100 m a.s.l. - on a north-west facing slope on the path that leads to Sukkertoppen (personal communication from Holt Hancock). Snow pits have been excavated during the field campaign. The selected areas have been nearby stations "Lia 100", "Vann 100" and "Nybyen". These areas have been investigated roughly twice a month. The snow pit measurements included: snow depth, temperature of the snow every 10 cm, definition of layers and their hardness, definition of crystal type and size in each layer. Other data has been obtained from the website RegObs (RegObs, 2018). Snowpack and avalanche observations can be uploaded on this website from any registered users, hence not all the observations from the investigated area were not enough accurate to be included in this work.

### 3.2 Methods

The dataset has been quality checked visually with MATLAB plots. Parts of the time series had to be taken away due to instrument failures. In particular, the WindLogger in Vannledningsdalen had a power failure shortly after the deployment and got fixed only on March 15th, hence its data are...
available only from this date on. The snow data from the station on Sverdruphamaren had numerous fluctuations so they have been completely discarded. The elements of the time series have been corrected using a running average that took into consideration a one hour time frame surrounding the individual point. Due to the activation threshold for the wind speed and directions, periods with winds lower than 1 m/s were removed. The whole wind speed dataset has been used to calculate the averages. Hourly averages of each variable have also been calculated and used to have a common time resolution when comparing data from Longyeardalen with records from Gruvefjellet and the airport.

Data from snowpits has been obtained according to the guidelines of American Avalanche Association and National Avalanche Center (2004) and has been represented using the software Snowpilot (Snowpilot, 2018).

Statistical methods have been used to compare data from the field campaign with data from the AWS on Gruvefjellet and at the airport. As first, the Pearson correlation coefficient was used to find the degree of correlation among the sites. This coefficient is defined (Wilks, 1995) as

\[ r_{xy} = \frac{1}{n-1} \sum_{i=1}^{n} \frac{(x_i - \bar{x})(y_i - \bar{y})}{s_x s_y} \]  

(4.1)

where \( n \) is the number of data, \( x \) and \( y \) are the individual values for a certain parameter from field and airport respectively, \( \bar{x} \) and \( \bar{y} \) are the averages, \( s_x \) and \( s_y \) are the standard deviations. The latter are defined (Wilks, 1995) as

\[ s_x = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2} \]  

(4.2)

The Pearson correlation coefficient \( r_{xy} \) potentially displays values between -1 and +1, where the extremes express a perfect fitting while values closer to 0 represent no correlation.

Another way to compare the time series is the use of the root mean square error, defined (Wilks, 1995) as

\[ RMSE = \sqrt{\frac{\sum_{t=1}^{n} (\hat{y}_t - o_t)^2}{n}} \]  

(4.3)

where \( \hat{y}_t \) are the data for the forecast and \( o_t \) are the data from the valley. The RMSE displays the concentration of the sample around the line of best fit. In this case, values closer to 0 mean that the dispersion is low, hence the two dataset are very similar.

All these parameters have been calculated and processed using MATLAB, which is also the source of all the plots.
4 Results

4.1 Synoptic conditions

The analysis of the synoptic weather charts (MetOffice, 2018) allowed for the identification of the general conditions around Svalbard for the period between March 1st and April 11th, 2018. In early March there was no significant synoptic activity in the area, with weak low pressure systems moving from East to Southwest. A high pressure system gradually settled on Svalbard from March 7th, rising up to 1034 hPa on March 9th and lasting until the 15th. Afterwards, a 978 hPa low pressure system started to move in from West, resulting in a warm spell on March 17th. On the following day, its occluded front was moving southwards. On March 20th and 22th low pressure systems were located in the Fram strait but they didn't reach Svalbard. Then, between March 26th and 28th, a 1022 hPa high pressure system was sitting southwest of the archipelago. In the following days, a low pressure system was moving eastwards in the Barents Sea, southeast of Svalbard, followed on April 1st by an occluded front moving southwards from eastern Svalbard. Afterwards, a 1020 hPa high pressure systems moved, influencing the region until the passage, between April 9th and 10th, of a low pressure system moving eastwards.

4.2 Local meteorological conditions

4.2.1 Temperature

The temperature (Figure 5a) ranged between -20°C and 1°C during the field campaign with higher values occurring during the cyclonic activity of March 17th, 28th and April 10th. Due to the difference in heights, Gruvefjellet site had an average temperature 2.5°C lower than the two sites located in the valley, never exceeding the melting temperature. The potential temperature (Figure 5b) has been used in order to have a common reference. In this frame Gruvefjellet had a higher average than the other stations, with $\theta_{mean} = -12^\circ\text{C}$, while the two valleys recorded $\theta_{mean} = -13.5^\circ\text{C}$. It is significant to remark that the warming in the week March 11th-18th initially hit only the plateau.
Figure 5. Hourly evolution of (a) temperature and (b) potential temperature at the three field sites: Gruvefjellet (green), Longyeardalen (red) and the airport (blue).

4.2.2 Precipitation

The field setup was not equipped to catch precipitation data, which has been obtained by the official station at the airport and compared to daily manual observations in Longyeardalen. The intrinsic difficulty in catching precipitation, as well as the particularly windy and dry conditions typical of Svalbard, did not allow for the acquisition of quantitatively accurate data for the precipitation events. It was thus decided that, in terms of precipitation, the dataset had to be divided among days with and without precipitation, specifying the type of the latter. Precipitation occurred only in solid form during the field campaign. Snowfall occurred between March 16th and 19th, on March 28th and on April 10th.
4.2.3 Wind Direction

![Graph showing wind direction over time for three sites: Gruvefjellet, Longyeardalen, and the airport.](image)

**Figure 6.** Hourly wind direction at the three field sites: Gruvefjellet (green), Longyeardalen (red) and the airport (blue).

![Graphs showing wind direction for Gruvefjellet, Longyeardalen, and the airport, with wind direction in degrees.](image)

**Figure 7.** Hourly wind directions during the field campaign.

The analysis of the general evolution of the wind direction (Figure 6) and its distribution (Figure 7) reveal strong differences among the three sites. Gruvefjellet seems to have a quite evenly distribution in the zonal winds, while for the meridional component northerly winds are almost inexistent. The result is a prevailing southeasterly flow. Longyeardalen site reveals a strong southerly component, in good agreement with the topography of the valley. Also the airport site seems to be biased by its valley, Adventdalen, with a strong easterly component.
Gruvefjellet is reasonably the station that better captures the synoptic scheme due to its privileged position on the top of a plateau (Figure 7). Consequently, the wind direction dataset has been divided in 4 subsets depending on the wind direction at this site, as shown in Figure 8. This choice was also due to the poor variability in the wind direction data observed at the other two stations.

For the northerly component, it can be seen that Gruvefjellet itself is strongly biased by fluxes from Northwest, which is the direction that presents less obstacles. In this case, the official station at the airport reports mostly winds from southeast, while the station in Longyeardalen records southerly flows. In both the cases, the prevailing directions are the same of the main structure of the valley.

In the case of easterly winds at Gruvefjellet, winds at the airport are again southeasterly and winds in Longyeardalen are also southeasterly despite their generally southerly flow with all other wind directions at Gruvefjellet.

When Gruvefjellet records southerly flows, the airport reports weak easterly winds, as a sign that the mountains to the south shield this station from this weather feature. In Longyeardalen, the southerly component is the strongest than in all the other cases, as the wind aloft strengthens the customary southerly flow typical of the valley.

Winds from west are associated with two different flows at the airport, as it seems that northwesterly and easterly flows are typical in this case. While the first well agrees with the winds
aloft, the latter might be a sign of the strength of the winds outgoing Adventdalen. In Longyeardalen, the records still display southerly flows.

4.2.4 Wind Speed

![Graph showing wind speed at 10 m at three field sites: Gruvefjellet, Longyeardalen, and the airport. Data for Gruvefjellet and Longyeardalen are extrapolated by records at 3 m using the logarithmic wind law.]

Figure 9. Hourly wind speed at 10 m at the three field sites: Gruvefjellet (green), Longyeardalen (red) and the airport (blue). Data for Gruvefjellet and Longyeardalen are extrapolated by records at 3 m using the logarithmic wind law.

Wind speed at 10 m displayed a similar general trend for the three stations, despite specific events having different outcomes on the field sites (Figure 9). Gruvefjellet station, on the plateau, displayed a mean wind speed of 5.4 m/s and standard deviation of 3.3 m/s, with several peaks above 10 m/s and values up to 20 m/s. A similar behavior has been observed at the airport, with an average of 5.7 m/s and a standard deviation of 2.8 m/s. The peaks followed the evolution recorded aloft. Longyeardalen exhibited a lower average speed, 3.8 m/s, as well as a lower standard deviation of 2.4 m/s. Strong winds aloft not always meant the same conditions in the valley, where the peaks have been in the order of 10 m/s, with hourly values never exceeding 12 m/s.
4.3 Wind channeling

What emerges from this general analysis is that both the valleys Adventdalen and Longyeardalen experience winds which often differ from the synoptic conditions. This could be caused by wind channeling due to their topography. To better understand the nature and the magnitude of the differences from the conditions aloft, three different cases are shown. These cases have been selected to show different types of valley circulation (Chapter 2.2), with downward momentum transport and forced channeling during the passage of a cyclone (March 17th) and the thermal circulation induced by the stable conditions provided by a high pressure system (April 8th). A third case is presented to illustrate the behavior of the small gully Vannledningsdalen.

4.3.1 Case 1: March 17th

![Chart](image.png)

**Figure 10.** (a) Winds direction, (b) wind speed and (c) potential temperature recorded on Gruvefjellet (green), in Longyeardalen (red) and at the airport (blue) on March 17th.

On March 17th Longyearbyen was being hit by a snowfall caused by a cyclone which reached Svalbard on the previous days and produced a significant increase in temperature. The 978 hPa low pressure system was causing winds to be easterly, as the station on Gruvefjellet reported as well (Figure 10a). The airport reported wind from East-Southeast, a condition similar to the flow on the
plateau. Wind speed never fell below 6 m/s and it peaked up to 15 m/s, following the evolution of the slightly higher speeds recorded on Gruvefjellet (Figure 10b). In Longyeardalen the average wind speed was 5 m/s, with no significant variations, opposed to the other two sites. The overall increase in temperature has been of more than 15°C within 48h, while in Figure 10c only the maximum of this curve is shown. The increase of the potential temperature has been equal in all the stations, despite the (expected) difference in the time series of temperature for the various stations, which sit at different heights.

![Graphs showing correlations and RMSE](image)

**Figure 11.** Correlation between (a) wind speed at 10 m and (b) wind direction among Gruvefjellet (X axis) and the airport (Y axis) on March 17th. Correlation between (c) wind speed at 10 m and (d) wind direction among Gruvefjellet (X axis) and Longyeardalen (Y axis) on March 17th. Blue circles are the samples, red line indicates a perfectly linear correlation. On the top of each graph are indicated the correlation coefficient and the RMSE.

Correlations of $r = 0.76$ for the wind direction and 0.87 for the speed confirm that the conditions at the airport were correlated to the winds aloft (Figure 11a and b). The RMSE for the wind direction is 22° while for the speed it is 2.9 m/s. This latter value express a certain difference in the mean speed at the two locations, probably caused by friction as the wind enters Adventdalen and gets slowed by the surrounding topography.
Poor correlations were found among the winds in Longyeardalen and Gruvefjellet (Figure 11c and d). In particular it can be seen that despite the almost constant wind direction on the plateau, wind direction in the valley ranged between 50° and 350°. The RMSE for this parameter is in fact extremely high, 119°, due to the lack of a stable value. RMSE is high also for the wind speed, 8.1 m/s, confirming that overall the conditions in Longyeardalen were different from aloft.

![Figure 12](image_url)  
**Figure 12.** Estimation of the stability in Longyeardalen using Richardson number (green) and z/L (red) on March 17th. Each point represents a ten minutes average.

In terms of atmospheric stability, Ri and z/L have been analyzed but the magnitudes were rarely exceeding zero (Figure 12). This was caused by extremely small differences among the values from the two temperature sensors which were used to calculate the stability. This was a sign that turbulence was occurring, mixing the air at least down to 1 m height. If this is combined with the knowledge of the synoptic situation, it can be pointed out that the atmosphere was weakly stable or neutral.

All in all, the two valleys displayed two different behaviors: while Adventdalen was following the general synoptic conditions, Longyeardalen was influenced by it in a non-linear way. In fact, given the hints of the wind direction variations and the poor stability, it has been concluded that
downward momentum transport from aloft was creating turbulence at the bottom of the valley, with the subsequent results which have been observed. This means that, in this case, the easterly winds caused by the synoptic activity have been strong enough to intrude the meridionally oriented valley and change its local weather. Hence, a correlation of some type could be found, given more precise data and different statistical tools than the Pearson correlation coefficient. Conversely, the good linear correlation recorded at the airport is a sign that the conditions aloft were extending within Adventdalen with few alterations. In particular, the decrease in wind speed and the turn in the direction suggest that the wind was locally channeled in the valley in an episode of forced channeling in which the valley walls steered the synoptic flow and erased the cross-valley component.

4.3.2 Case 2: April 8th

![Graphs showing wind direction, wind speed, and potential temperature over time.](image)

Figure 13. (a) Winds direction, (b) wind speed and (c) potential temperature recorded on Gruvefjellet (green), in Longyeardalen (red) and at the airport (blue) on April 8th.

On April 8th a 1017 hPa high pressure was located over Svalbard while a weak low pressure system was approaching from West. The overall synoptic conditions were hence a weak westerly flow. On Gruvefjellet the wind met the expectations while the two valleys were displaying a different
behavior (Figure 13a and b). The wind direction at the airport was easterly until 10 A.M., when a turn occurred, resulting in a southerly flow which slowly turned again easterly by the late afternoon. In the morning the wind speed had an average around 2 m/s while after the southerly turn it started to increase stably from a magnitude of 1 m/s to 4 m/s. Longyeardalen displayed a constant southerly flow throughout the whole day. Also the wind speed didn't have significant variations, with an average of 2 m/s. It is remarkable to notice that in the late evening, when the wind on Gruvefjellet increased, the same parameter decreased in the valley. The potential temperature had a moderate change during the day (Figure 13c), with a similar trend in all the stations but different magnitudes. It is also significant to note that the plateau had initially a higher potential temperature (-10°C) then the two stations in the valleys Adventalen (-16°C) and Longyeardalen (-14°C). On the exposed plateau, the potential temperature had a maximum increase of 5°C by midday, while at the airport and in Longyeardalen the increase has been in the order of 7°C and 4°C respectively. In the afternoon the values stabilized, even though the potential temperature maintained a 4°C difference between Gruvefjellet and the other two stations.

**Figure 14.** Correlation between (a) wind speed at 10 m and (b) wind direction among the airport (X axis) and Gruvefjellet (Y axis) on April 8th. Correlation between (c) wind speed at 10 m and (d) wind direction among Gruvefjellet (X axis) and Longyeardalen (Y axis) on April 8th. Blue circles are the samples, red line indicates a perfectly linear correlation. On the top of each graph are indicated the correlation coefficient and the RMSE.
The linear correlation indexes between Adventdalen and Gruvefjellet have been quite low for both the wind parameters (Figure 14a and b). The RMSE parameter of 1.2 m/s indicates that the mean difference in the wind speed between the locations has been small. The same statistical parameter gives a value of 136° for the wind direction, as a result of the two almost opposite flows recorded.

The correlation has been low also among Longyeardalen and Gruvefjellet (Figure 14c and d). The RMSE value of 1.2 m/s displays the same minimal variability that has been found in the other valley. The wind direction has a RMSE of 84°, indicating the flow on the plateau has been almost perpendicular to the main direction Longyeardalen.

![Richardson number and z/L](image)

**Figure 15.** Estimation of the stability in Longyeardalen using Richardson number (green) and z/L (red) on April 8th. Each point represents a ten minutes average.

The Richardson number and the static stability both indicate a stable atmosphere, with Ri between 2 and 5 during the day, and a neutral period around midday (Figure 15). These latter values are caused by a decrease (from 0.5°C to around 0°C) in the temperature difference between the two sensors used to define the gradient. It is unlikely that such change is due to turbulent mixing, as the wind speed didn't have significant changes from the previously recorded low values.
The cloud cover had no variability as well, and the almost midnight sun conditions exclude relevant changes in the radiation.

The two valleys exhibited the same type of circulation during the morning of April 8th, even though the local wind directions were different. The weak wind coming from west was not able to intrude the valleys, where a stable boundary layer was present due to the high pressure system which affected the area in the previous days. Within this stable boundary layer, local processes were going on undisturbed, with the onset of thermal circulations caused by the temperature differences within the valleys. These thermal circulations had winds with magnitudes in the order of 2 m/s and blew down-valley in the form of katabatic winds. Two events are of particular interest. Firstly, the neutral stratification period in Longyeardalen might be the result of the temperature increase due to the approaching cyclone. Such advection of air would have temporarily cancelled the stable conditions caused by the snow covered ground. The second remarkable event is the almost abrupt change in the wind direction at the airport. The onset of a pure southerly flow is not consistent with the topography of the valley (NW-SE) neither with the westerly winds aloft. The cause is probably a combination of the two, with the westerly flow starting to superimpose on the valley circulation in the early afternoon. The same speed magnitude resulted in the cancelling of the zonal component, with a weak southerly flow.

4.3.3 Case 3: Vannledningsdalen on March 17th

The small gully Vannledningsdalen displays even more clearly the channeling effects that occur in the area. This case focuses on March 17th, whose weather conditions have been largely discussed (Chapter 4.3.1). The wind direction in this gully has been almost stably southeasterly during the whole day, with a southerly turn in the late afternoon (Figure 16a). The wind speed has been moderated, with values above 5 m/s during the first half of the day, before decreasing when the wind veered (Figure 16b). The temperature, which was recorded at two sites within the gully, had firstly a slight increase and then decreased in the evening (Figure 16c).

The wind data shows a strong dependency on the topography, which is oriented SE/NW, descending from Gruvefjellet down to Longyearbyen. The side walls clearly caused a force channeling of the flow descending from the plateau and aligned it with the direction of the gully. The downwards momentum transport observed in Longyeardalen did not occur in this valley, as a sign that the forced channeling was prevailing. The wind speed initially followed the trend and the magnitudes reported higher up, then in the afternoon it flattened on the values recorded in Longyeardalen. This was probably due to the wind conditions aloft. When the downward momentum transport was not influencing Longyeardalen anymore, its circulation prevailed in
Vannledningsdalen or at least in lowest part of the gully, despite the strong winds recorded aloft. The temperature here followed the behavior of the other two stations, as further evidence that in this case the gully did not have its own circulation but was rather following the prevailing forcing.

It is clear that Vannledningsdalen experienced an event of forced channeling during the morning of this day, with the winds from the plateau being redirected along the gully. The afternoon and the evening instead saw the restoring of the thermal circulation in Longyeardalen, which then extended partially inside the gully.

![Graphs showing wind direction, speed, and potential temperature](image)

**Figure 16.** (a) Winds direction, (b) wind speed and (c) potential temperature recorded on Gruvefjellet (green), in Longyeardalen (red) and in the gully Vannledningsdalen (blue) on March 17th. The black lines in (a) represent the orientation of Vannledningsdalen.

### 4.4 Local snow conditions

The analysis of the snow conditions was originally planned to be carried on 3 stations: Lia, Nybyen and Sverdruphamaren. Unfortunately, the latter displayed extreme variations in many parts of the record and hence it has been discarded due to the unphysical meaning of its data.

If days with precipitation are excluded, considering that no avalanches occurred and the temperature has rarely been above freezing temperature, it can be understood that transport due to the wind plays an important role in the evolution of the snowpack at least in terms of snow depth.
Two cases are shown to display the impact of a sudden increase in wind speed (March 4\textsuperscript{th}-6\textsuperscript{th}) and the effect that a frozen surface has on the overall transport (March 7\textsuperscript{th}-12\textsuperscript{th}).

4.4.1 Case 1: March 4\textsuperscript{th}-6\textsuperscript{th}

The two snow stations exhibit different behaviors (Figure 18). The snow depth in Lia was constant until a sudden increase on March 5\textsuperscript{th}, which lasted some hours before the initial values were restored. In Nybyen, a constant decrease was observed, with no significant fluctuations.

In Lia, during the considered period the overall loss of snow was 4 cm. Initially, the depth remained the same, but during March 5\textsuperscript{th} it increased by 5 cm when the wind in Longyeardalen was above 8 m/s. After the wind decreased again in the valley, the recoded snow depth returned to its original value. The surface wind speed recorded in Lia 200, at the corner between the two valleys, was averaging 6 m/s for the whole period and had a trend in good agreement with the airport data.
In Nybyen, the decrease in the snow depth continued throughout the whole considered period, while moderate easterly winds (8 m/s) were recorded on Gruvefjellet and weaker flows were observed in the nearby valley.

The temporary increase in snow depth occurred on March 5th hints that snow transportation phenomena as creep and saltation were ongoing in Lia during that period. The recorded values are hence not a real accumulation of snow but are rather the noise caused by the snow particles moving within the saltation layer due to the moderate wind. The transported snow was backscattering the signal from the sonic anemometer used to measure the snow depth, resulting in false records of deeper snow. This effect ended its contribution as soon as the wind got weaker. This is a hint that snow transport was occurring, as the final overall decrease in snow can prove. The snow has probably been moved by the easterly flow recorded in the near to the site. In terms of the prevailing wind direction, no relevant correlations could be observed between the snow station and the wind anemometer on Lia, as a sign that the snow station itself was influenced by the easterly wind only.

![Figure 18.](image-url)
when the whole of the Longyeardalen valley was. The behavior of snow depth in Nybyen seemed to be more consistent with the wind evolution recorded on the plateau than with the station in the valley, but in both cases the linear correlation with the third and fourth powers of the wind speed fails to prove such evidence. Due to the intensity of the wind, creep and saltation are expected to be the causes of the decrease in the snow depth, with the snow being removed from the slope.

4.4.2 Case 2: March 7th-12th

Snow depth has been stable between March 7th and 9th in Lia, while in Nybyen a loss of 2 cm was observed while the wind in the valley was under 2 m/s and on the plateau was on average 3 m/s (Figure 19). After the wind in the valley increased up to 6-8 m/s, Lia experienced an increase of 6 cm in the amount of snow within some hours. After the wind decreased again on March 10th, the snow depth ceased increasing. In particular, even when on March 12th the wind reached the same magnitudes, no changes were observed.
Small increases in the snow depth were also observed in Nybyen, but they were short lasting events. In particular, the main trend has been the removal of snow, which happened slowly despite the moderate winds recorded on the plateau throughout the whole considered period.

The initial increase in the snow depth occurred in Lia during a period of strong winds is a hint that creep and saltation processes were occurring. When the flow got calmer, saltation stopped, while creep probably continued in a measure that is not possible to quantify due to the resolution of the data. The poor variation in the snow depth despite the strong winds on March 12th has been attributed to the presence of frozen snow that would have required much more energy to be transported.

![Figure 20](image.jpg)

**Figure 20.** Detail of the upper part of the snow pit in Lia 100 performed on March 14th. The uppermost layer was extending for 7 cm and had a strength classified as K.

A confirmation that the snow packing could be the cause of this lack of observed transport is provided by the snow pit performed on March 14th on Lia, which shows that on the surface there was a 10 cm layer of hard snow which was preventing larger transport phenomena (Figure 20). This has been assumed to be true also for the station in Nybyen.
5 Discussion

The local weather conditions in Longyeardalen and at the airport were analyzed and compared to the synoptic records from the plateau Gruvefjellet to understand if the data from the official station at the airport were representative for the valley. Furthermore, the impact of the local weather on the snow conditions in Longyeardalen was investigated, with the ultimate aim to improve the avalanche forecasts in the area of the settlement Longyearbyen.

5.1 Wind channeling

Overall, despite a prevailing southeasterly component aloft, the prevailing wind directions are easterly and southerly in Adventdalen and Longyeardalen respectively, with the smaller valley having on average weaker winds (3 m/s) than the airport and the plateau sites (6 m/s). An analysis of the wind conditions has been carried out to distinguish the different types of valley circulations. The wind data from both Longyeardalen and the airport have been divided in 41 sets lasting 24 h. Each of these sets has then been compared with the synoptic conditions recorded on Gruvefjellet on the same date. Depending on the magnitude and on the deviation from these latter data, a type of circulation has been assigned to each of the samples, as displayed in Figure 5.1. Pressure driven channeling was united with forced channeling, as the quality of synoptic data obtained from the synoptic charts did not allow to have a well defined wind direction for the winds aloft.

Table 3. Classification of the prevailing circulation in the two valleys on a daily scale, 41 samples.

<table>
<thead>
<tr>
<th></th>
<th>Thermal</th>
<th>Downward momentum</th>
<th>Pressure driven/forced channeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longyeardalen</td>
<td>46%</td>
<td>44%</td>
<td>10%</td>
</tr>
<tr>
<td>Airport</td>
<td>20%</td>
<td>0%</td>
<td>80%</td>
</tr>
</tbody>
</table>

From Table 3 emerges a difference in the behavior of Longyeardalen and Adventdalen. In Longyeardalen, thermal circulation and downward momentum prevail, while in Adventdalen the terrain driven circulation prevails despite the probable presence of a thermal component. Theory (Chapter 2.2) indicates that the cause of the difference lies probably in the shape of the valleys: Adventdalen is long and wide, with relatively low side walls, while Longyeardalen is shorter and deeper, if compared by height of the slopes on its sides.

This means that it is easier for the winds aloft to intrude inside Adventdalen and play a major role in influencing the wind speed and partially the wind direction. Due to the temperature differences between the fjord and the mountains at the edges of the valley, a thermal component is
expected but it gets hidden most of the times by the strength of the terrain channeled winds. It is possible to observe it during periods with weak southerly winds, when the along valley flow is undisturbed.

The relatively protected position of the bottom of Longyeardalen causes it to be less influenced by the wind blowing on the plateau. Furthermore, the presence of two glaciers on the uppermost edge induces a thermal circulation with katabatic winds flowing down towards the fjord. These flows are rather weak, 1-2 m/s, but they are constantly observed during periods with a stable atmosphere. In cases of unstable conditions, or when the winds on the plateau are particularly strong, the circulation aloft extends within the valley, enhancing mixing and causing cross-valley winds. Forcedly channeled strong southerly flows can superimpose to the thermal circulation, resulting in moderate meridional winds.

The case studies of March 17th and April 8th evidence the complexity of the wind circulation in the valleys. In fact, episodes like the downward momentum transport in Longyeardalen (March 17th) and the sudden turn of the wind at the airport (April 8th) are not caused by a rapid change of the conditions aloft but are rather the result of a forcing that builds up with time. Furthermore, these events could last some hours (like the downward momentum transport of March 17th) or extend for more than a day (as the forced channeling at the airport on the same date). Other evidence from the case studies shows that the changes in the prevailing local circulation are not occurring at the same time. This is again mostly due to the topography, as the wind directions that trigger particular types of circulations are different and depend on the orientation of the valley. It is also understood that the same wind speed aloft might not always lead to the same circulation, as the current weather conditions in the valley must be taken into account as well.

The gully Vannledningsdalen is heavily influenced by the wind circulation in Longyeardalen (31% of the cases) and by the down-valley winds from Gruvefjellet (69% of the cases). Due to its narrow shape and to its orientation that favors the prevailing southeasterly winds reported on the plateau, this gully is primarily influenced by the conditions on Gruvefjellet, with an equal share among forced channeling (during stable conditions in Longyeardalen) and downward momentum transport (during unstable conditions). Due to the topography, in the case of westerly winds aloft, the prevailing wind direction in Vannledningsdalen is up-valley with speeds that are in good agreement with what is recorded in Longyeardalen.

5.2 Snow transport
No significant linear correlations have been found among the snow depth in Lia and Nybyen and powers of the wind speed. Anyway, if the hourly snow depth variation is compared to the wind
speed, it is clear that wind contributes in the redistribution of snow in the area. This is in agreement with the earlier findings from Hancock (2016). The lack of correlation is then probably caused by the low resolution of the data, with the snow depth given in cm and the wind speed being calculated in another location. Furthermore, as there is more than one snow transport mechanism, a unique general formula for the correlation cannot be defined (McClung & Schauer, 2006).

Despite the lack of a conclusive finding, some information can be obtained from the dataset. First of all, the two stations behave in an almost opposite way in response to the wind. The constant decrease in snow depth in Nybyen seems to communicate that the wind acts in a destructive way, removing the snow from this exposed location on the slope. Anyway, some episodes with minor constructive behavior have been identified. During these events, moderate southeasterly winds recorded on the plateau were extending all the way down to the station in the valley. In these cases, when downward momentum transport and forced channeling were prevailing on the thermal circulation, the snow depth increased by some centimeters for 24-48h due to the snow transported from the overlying plateau. It seems then that the prevailing wind component in this location is the same that is recorded on the bottom of the valley Longyearedalen. When the forcing above is dominating, the valley records similar values to Gruvefjellet, hence data from the valley can be useful to parameterize the wind higher up on the slopes. It is important to remark that Nybyen station is not on the edge of the plateau, but it is some tens of meters downslope within the valley, hence this conclusion does not apply to the cornices growing above, at the same height of Gruvefjellet, where other investigators have assessed that the prevailing easterly winds have a constructive impact (Vogel et al., 2012).

From the case studies it is understood that Lia, due to its position, is influenced by both Longyearedalen and Adventdalen. The wind anemometer placed some tens of meters upslope recorded data which are consistent with the bigger valley but this is due mostly to its relatively protected position. The snow station, conversely, lies on the lee side of the wind coming from Adventdalen. The overall result is hence that the wind from this valley contributes transporting snow to the site with creep and saltation processes while the wind from Longyearedalen sweeps away the snow. Anyway, the removal of snow is effective only if the wind is strong enough and if the ground is not frozen. During events like between March 9th and 10th the wind seems to have a constructive effect when in the order of 5 m/s. An opposite contribution has been observed around April 2nd and 9th, when the values reached 10 m/s, while with winds between 1 m/s and 3 m/s the impact is small and alternates between a constructive and destructive effect without a clear distribution.
5.3 Representativeness of the data from the airport

Data provided by the AWS at the airport site are used daily in the Norwegian weather model AROME Arctic in order to obtain forecasts for Svalbard and in particular for the settlement of Longyearbyen. These data are also used as inputs for the avalanche bulletin for Nordenskiöldland. The representativeness of these data has been questioned, with a focus on the real conditions in Longyeardalen and the valley walls.

5.3.1 Temperature

![Correlation plots](image)

**Figure 21.** Correlation of the temperature among (left) the airport (X axis) and Gruvefjellet (Y axis) and among (right) the airport (X axis) and Longyeardalen (Y axis) during the field campaign. Blue circles are the samples, red line indicates a perfectly linear correlation. On the top of each graph are indicated the correlation coefficient and the RMSE.

Temperature at the airport is in well agreement with the synoptic conditions captured on Gruvefjellet (Figure 21a) and it has been compared with data from Longyeardalen (Figure 21b). The correlation among the two sites is 0.95, a sign that the temperature in the small valley is strongly conditioned by the synoptic forcing. A RMSE of 1.1°C is an indication that some deviations occur. These cannot be attributed solely to the difference in height between the two stations, as the difference is only 59 m. The potential temperature has been analyzed in order to
eliminate the influence of the height component and the RMSE was again 1.1°C. This hints that local processes influence the behavior of at least one of the two stations. The 1.1°C variation is well distributed among the data, as the difference in the average temperature between the two stations is 0.2°C. It is hence concluded that temperature data from the airport are representative for Longyeardalen. This is true despite the presence of local contributions, as they do not bias the data in a constant way.

5.3.2 Precipitation

It was not possible to obtain precipitation data from Longyeardalen, but data manual observations in the valley agree with records from the airport in both the type of precipitation and time (on a daily scale). The amount of precipitation and hourly data were not available due to the resolution of the manual observations.

5.3.3 Wind Speed

![Wind Speed Correlation](image)

**Figure 22.** Correlation of the 10 m wind speed among (left) the airport (X axis) and Gruvefjellet (Y axis) and among (right) the airport (X axis) and Longyeardalen (Y axis) during the field campaign. Blue circles are the samples, red line indicates a perfectly linear correlation. On the top of each graph are indicated the correlation coefficient and the RMSE.
Wind speed at 10 m from the AWS at the airport has been compared with the corrected data obtained at 3 m height from the other two stations. It is hence believed that this process has introduced some errors in the magnitude of the wind, as there is no guarantee that the conditions to use the logarithmic parameterization were met.

For the speed, the correlation among the plateau and the official site at the airport is 0.80, with the trend being similar at the two sites and a RMSE of 2.0 m/s (Figure 22a). This indicates that despite the valley circulation and the topographic forcing, most of the momentum is conserved and reaches the airport. When the wind speed at the airport is under 6 m/s the plateau indicates lower speeds, while for values exceeding 8 m/s Gruvefjellet generally reports higher magnitudes. This is stressed even more in the case of stronger winds. These systematic deviations are probably mostly due to the use of the logarithmic formula to calculate the flow on the plateau. All in all, the wind speed at the airport provides a good parameterization for the conditions on the plateau.

A comparison with the station in Longyeardalen does not provide the same conclusion despite the fact that the general trend is similar most of the time (Figure 22b). It is in fact observed that the data in the valley are biased to lower magnitudes, with a correlation factor of 0.52 and a RMSE of 3.2 m/s. As a general rule, when the wind at the airport is lower than 6 m/s Longyeardalen underestimates it, while when the values exceed 8 m/s the small valley reports higher magnitudes. This is anyway not true for all the cases, as some periods exhibit significant differences in the trend among the two stations. These periods correspond to the downward momentum transport events in Longyeardalen. During these events, the valley site records speeds which are in good agreement with the synoptic forcing and, hence, with the airport. Conversely, when the thermal circulation is the prevailing phenomenon, lower speeds are observed. It is hence concluded that to represent Longyeardalen well it might be generally enough to decrease by 3 m/s the records from the airport, having a critical approach in order to remove such correction factor when the conditions are favorable for phenomena of downward momentum transport. In a frame of physically improving the network, data from the plateau (with a correlation of 0.61) could be used.

5.3.4 Wind direction
Wind direction is the variable that the valley circulations influence the most. A comparison between synoptic charts and data from Gruvefjellet seems to indicate that the latter well represents the conditions aloft, hence is not extremely biased by the surrounding topography. The same is not true for the two stations sitting in the valleys, where the relatively large variability recorded on the plateau is drastically narrowed down to a main component, which is southeasterly at the airport southerly in Longyeardalen.
The wind direction is strongly biased by the shape of Adventdalen, resulting in the wind being southeasterly most of the time (Figure 23a). As a result, the correlation among the airport and the wind direction aloft is 0.55, with a RMSE of 75°. It is important to remark that the dataset could be divided in two parts: one that displays southeasterly directions even when the wind aloft turns and one that follows an almost linear correlation. These two components exhibit the two behaviors of the valley. The first case is due to the forced and the pressure driven channeling which force winds in the range between southerly and easterly to be southeasterly, enhancing the thermal circulation the valley. As these winds are common in the region, this situation represents most of the cases. The other case involves winds in the range between westerly to northerly. In this case the wind direction at the airport site follows the behavior of the synoptic forcing, as winds coming from these directions are not influenced by topography, since the footprint on the station consists in several tens of kilometers of fjord. It is hence understood that data from this station are completely reliable in the case of westerly to northerly winds, as well as in the few cases when downward momentum transport prevails on the other circulations. In many other cases the forced channeling decreases the
variability shown on Gruvefjellet. Hence, the reliable part of the data should be integrated with wind direction records from the plateau.

As a result of the relative variability in the wind directions in both Longyeardalen and at the airport site, their linear correlation is 0, with a RMSE of 91° (Figure 23b). This latter value does not come as a surprise, given that the two sites experience mostly along-valley winds and the two valleys are almost perpendicular. It might be partially concluded that when one of the valley experiences an along valley-wind, the other is behaving in the same way. These conditions don't apply when relevant synoptic activity occurs, as during the cyclone around March 17th. It is anyway true that the exact wind direction at the bottom of Longyeardalen is of minor interest once understood that for most of the time the wind is down-valley. Furthermore, data from Gruvefjellet can be used to determine if the wind would be channeled in the valley or not.

5.3.5 Snow

Given to the lack of precise data for the precipitation, and due to the variability in the snow depth recorded at the field site, the accumulation of snow could not be evaluated quantitatively. What anyway emerges is the agreement among the increase in the snow depth and the snowfall days at the airport. In terms of snow transport, the data from the airport cannot provide a full understanding of the process, as it has been found out that large differences can onset among the field sites given particular synoptic forcing. Due to the position of Lia, the airport provides reliable wind speed and direction data, but there is the need to take into account the impact of the circulation in Longyeardalen. In this second valley, the sole use of data from the airport does not provide results that are useful in order to understand the snow transport. If a correction factor of 3 m/s a southerly turn of the direction are applied to the wind recorded at the official station, it is possible to qualitatively parameterize the forcing in Longyeardalen in the case of a purely thermal circulation. It is needed to keep track of the snow type and stratification in order to assess how effective can the wind forcing be.
6 Conclusion

The general wind direction for the weather aloft is probably better represented by the station in Gruvefjellet, due to its relatively flat surroundings. The stations at the airport and in Longyeardalen suffer from their position at the mouth/inside of a valley, which biases a large amount of the cases to show a southeasterly (at the airport) or southerly (Longyeardalen) flow even when it seems that the general conditions are not similar aloft. The wind recorded at the airport is mostly caused by the forced channeling in Adventdalen while in Longyeardalen a thermal circulation is prevailing. Despite these general results, it seems that the prevailing wind direction in the valleys can undergo significant changes during single 24-48 h events. In particular, the forced channeling of winds with a westerly component can induce a completely eastwards flow at the airport and hence in Adventdalen, despite the contribution from southeasterly winds which are the result of a thermal component of the circulation. In Longyeardalen the thermal circulation is present almost constantly, despite being occasionally enhanced by southerly winds which get forcibly channeled in the valley. In this valley, downward momentum transfer plays an important role in the case of winds with a strong zonal component, resulting in the production of turbulence which mixes the air inside the valley and stops the customary down-valley flows. The gully Vannledningsdalen is mostly influenced by the forced channeling and the downward momentum transport from the plateau aloft, but with westerly winds Longyeardalen becomes the primary source of the forcing, even though it is unclear how far the up-valley winds extend.

Wind channeling events induce snow transport with directions and magnitudes that differ from the official data provided by the station at the airport. It is thus important to forecast and follow the evolution of the local circulations within the valleys, as they have the potential to influence the evolution of the snowpack in a way that is different from what would be expected if only the official station is taken into account. The complexity of the topography makes it difficult to forecast when these episodes will occur exactly, but even a poor time resolution would be enough to start to actively use these data to run a snowpack model in order to predict slab avalanches from the slopes in Lia and partially above Nybyen. This could be done extending the setup of the snow stations adding a wind anemometer and integrating a snowpack model with the results from these stations (which are already providing real time data). A different conclusion is drawn for the cornices which grow at the edges of Gruvefjellet, endangering Nybyen from the very top of the slope. Literature expresses their dependency on the winds on the plateau but the current system lacks of considering these data. It is hence recommended to include the data from this latter weather station in AROME Arctic to correct the wind directions reported by the biased data from the airport.
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I dedica this work to my late beloved grandfather Sergio. I wish we could have shared the happiness of my graduation together.
References


