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Advanced prediction in polar regions and beyond

IS SVALBARD PREPARED FOR EXTREME RAINFALL?

Svalbard is an archipelago in the Arctic Ocean administered by Norway under the Svalbard treaty, midway between continental Norway and the North Pole (Fig.1). For the last 50 years, it has witnessed an annual mean temperature rise of 3-5°C (Hanssen-Bauer et al. 2019), with winter warm spells becoming more frequent (Peeters et al. 2019). The risk of increased frequency of precipitation in form of rain is an important climate change challenge affecting the archipelago during autumn and winter. Adaptations that settlements and the environment would demand, could set the scene for the rest of the globe. In order to make progress, we first need to have a better understanding of *extreme weather and climate events*[A] in Svalbard, which will lead to better predictions that improve the preparedness of local populations to deal with such events.

Fig.1. Location of Svalbard in the Arctic Circle.
Credit: adapted from The Guardian.

Upper photo: Landslide in mountainside above Longyearbyen, Svalbard, Thomas Nilsen, The Barents Observer

GLOSSARY

A

Extreme weather and climate events: The occurrence of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable at a particular location.

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CHAIN OF EVENTS

THE EVENT: Precipitation in the form of rainfall in the Svalbard archipelago.

In early November 2016, the temperature in the Svalbard archipelago was extremely high for that time of the year. On 7-8 November, the region was hit by extreme precipitation that, due to the warm temperatures, partly fell in the form of rainfall. The rain reached a peak in the evening of 7 November. A total precipitation of 86.8 mm was observed in 24h in Ny-Ålesund, a research town on the island of Spitsbergen (normal precipitation in November is around 33 mm) and 41.7 mm were observed at Svalbard Airport, next to Longyearbyen, the archipelago's administrative center (normal precipitation in November is around 15 mm) (Humlum et al. 2016; Fig.2). These precipitation values are above the estimated *100-year return period*[B] value (Hanssen-Bauer et al. 2019).

B

100-year return period: Return periods refer to the amount of time that passes on average between two consecutive events of similar magnitude for a given location. 100-year return period means that, according to historical data, the extreme event occurs on average once every 100 years, so it has 1% chance of occurring in any given year.

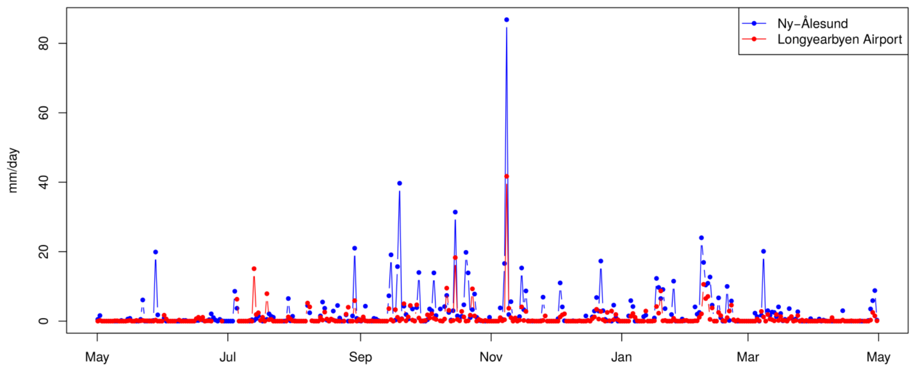

Fig.2. Observed daily precipitation from Ny-Alesund (blue) and Longyearbyen (red) from May 2016 to April 2017. Credit: Morten Køltzow, MetNorway.

THE IMPACT: Landslides and slush avalanches.

Heavy rain events can have a substantial impact on the characteristics of the snowpack and permafrost (Hansen et al. 2014). Often, although not always, extreme precipitation events are the triggering factor of landslides and slush avalanches. Such events are often followed by freezing conditions with potential impacts related to ground ice formation, which can require closing of roads and airports, affect the population mobility and reduce the income from tourism. Moreover, these types of events can also lead to starvation-induced mortality in populations of wild reindeer, by blocking access to the winter food resources.

C

Slush flows: Type of debris flow that consists in a rapid mass movement of water and snow. Slush flows are caused when water reaches a critical concentration in the snowpack due to more water inflow than outflow, which weakens the cohesion of the snow crystals, increasing the weight of the snowpack.

Following the November 2016 precipitation event, several landslides and *slush flows*[C] were identified by satellite imagery in Svalbard (Hanssen-Bauer et al. 2019; https://titan.uio.no/node/2009). Even snow avalanches were observed on slopes above 500 m altitude. Fortunately, evacuation of parts of Longyearbyen was done in advance and no major impact on humans or infrastructure was noted (Humlum et al. 2016). In fact, the particular November 2016 precipitation event only led to very limited actual impacts in the area compared to the potential damages. This was due to the warm conditions during autumn, that did not favour snow accumulation. At the same time, the upper *active layer*[D] (uppermost 20-30 cm) froze just before the event, preventing water infiltration and thus limiting slope failure and landslides. Had the rainfall happened before the freezing of the upper layer, the risk from landslides would have been much higher. More serious damages occurred during other precipitation episodes, such as the one in 2015 when, following a winter storm with snowfall, an avalanche buried houses and some people were injured (Indreiten and Svarstad 2016).

D

Active layer: Top layer of soil that freezes and thaws seasonally above permafrost.

THE CAUSE: Why did landslides happen?

On 7 November 2016, a high-pressure system that was centred over northern Scandinavia brought warm and moist air northward over the north-eastern Atlantic. The forced lifting of incoming warm and moist air masses over the mountains on Svalbard led to heavy precipitation, mainly in the form of rain (Fig.3).

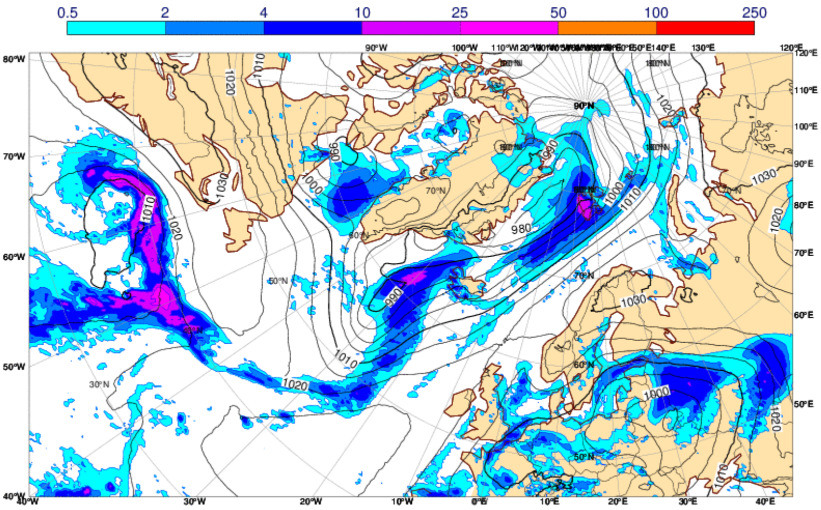

Fig.3 Mean sea level pressure (contour lines) in hPa on 7 November 2016 at 12:00h UTC and precipitation accumulated (coloured areas) in millimeters in the 6-hour forecast from 12:00-18:00 UTC the same day. Reddish tones indicate higher accumulated precipitation. Credit: Linus Magnusson, ECMWF.

Heavy rainfall events like this one are associated with certain large scale weather patterns[E]. The study of all major winter precipitation events in the past years (March 2016 to April 2018) conducted in APPLICATE, has revealed the *Scandinavian blocking*[F] weather pattern to be responsible for the major part of high-impact precipitation events on Svalbard, including rain on snow and rain on frozen ground. Although the event in November 2016 cannot be considered a 'typical' Scandinavian blocking, it still displayed anticyclonic circulation over northern Scandinavia, thus sharing common characteristics. Making an average of all Scandinavian Blocking events predicted in the past from 1981-2015, Fig.4 indicates higher than normal temperature and precipitation over the Svalbard archipelago during Scandinavian blockings.

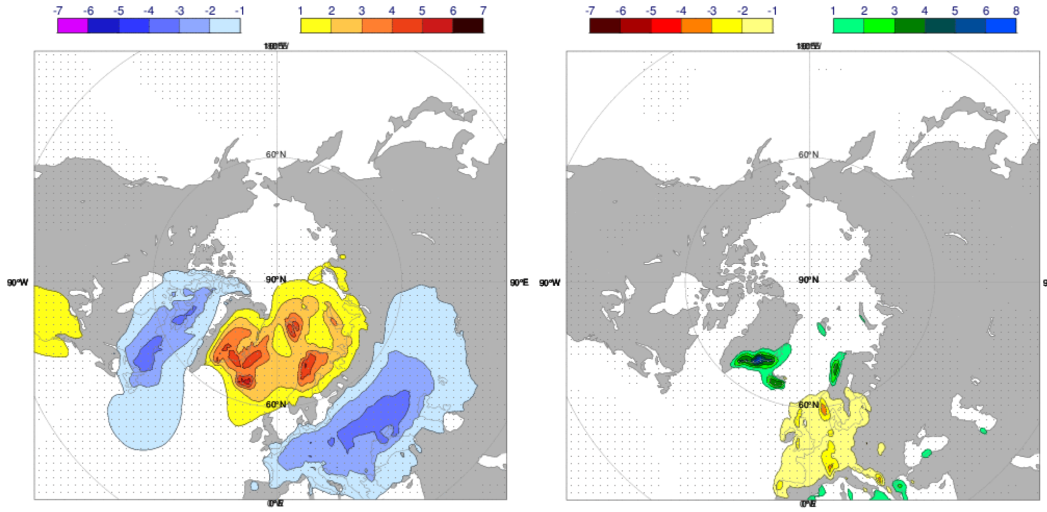

Fig.4. Deviation from normal in degrees Celsius (2-meter temperature, on the left) and in millimeters in 24 hours (precipitation, on the right) during winter Scandinavian blocking regime events. For temperature (left), the darker the red colour, the warmer as compared to the period 1981-2015, whereas for precipitation (right), the darker the blue colour the higher the total precipitation as compared to 1981-2015. Source: ECMWF System 5 seasonal *hindcasts*[G] for winter (DJF). Credit: Linus Magnusson, ECMWF.

APPLICATE PREDICTIONS

Two main ingredients are required for the prediction of heavy rainfall events in Svalbard:

- A model able to capture the enhanced precipitation over topography
- An accurate prediction of the large-scale flow that brings the warm and moist air to the archipelago

E

Large-scale weather patterns: Weather developments over a large area (caused by interactions of solar radiation, ocean, diverse landscapes and motion in space) that do not significantly change over several days. They are important to predict the development of the weather and atmospheric conditions for a longer period.

F

Scandinavian blocking: Blockings are large-scale patterns (see E) of high atmospheric pressure in middle to high latitudes that steer winds away from a region affecting temperature and precipitation. Scandinavian blockings are characterised by a high pressure system over northern Scandinavia and a low pressure system west and north of Svalbard that provide favourable conditions for the transport of heat and moisture from lower latitudes. This type of atmospheric setup is responsible for Arctic warm spells and the majority of the high-impact precipitation events in the Svalbard archipelago. See Woolings et al. 2018 for more information.

G

Hindcast: Forecast made for a period of the past using only information available before the beginning of the forecast.

For short-range forecasts (next hours to a few days), the model resolution needs to be sufficient to resolve the air movement over topography and capture the precipitation maximum. The accumulated precipitation in 24h was predicted on 7 November (Fig.5), providing an indication of the high intensity of the event. Results obtained with two different resolution models (ECMWF HRES[H] and AROME Arctic[I]) used in APPLICATE are displayed in Fig.5 showing that model topography in high-resolution is a prerequisite to adequately forecast local variations in precipitation.

H

ECMWF HRES: Forecasting system from the European Center for Medium-Range Weather Forecasts that provides a highly detailed description of future weather up to 10 days (~ 9 km grid spacing resolution) .

I

AROME Arctic: Regional short-range high-resolution forecasting system for the European Arctic with 2.5 km grid spacing (Müller et al. 2017, Køltzow et al. 2019).

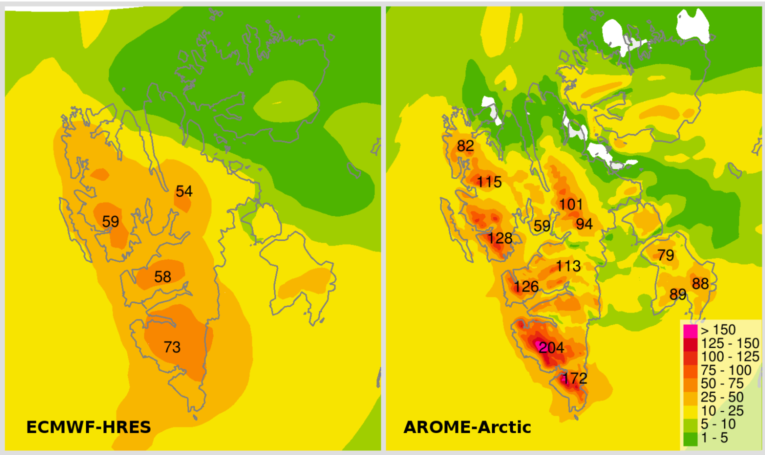

Fig.5 Accumulated precipitation in 24 hours (mm/24 hr) predicted on 7 November 2016 using the ECMWF HRES (~ 9 km grid spacing) (left) and AROME Arctic (2.5 km grid spacing) (right) models. Red colours indicate higher accumulated precipitation. Credit: Morten Køltzow, MetNorway.

Numerical Weather Prediction[J] models (next few days) predicted extreme values of temperature and precipitation for 7 November 2016 over the Svalbard archipelago already 6 days in advance, as shown by the *Extreme Forecast Index*[K] (EFI, Fig.6). The forecast shows the likelihood for extreme temperatures over large parts of the north-eastern Atlantic and the enhanced risk of extreme precipitation over Svalbard.

J

Numerical Weather Prediction (NWP): Most familiar form of weather model data on a day-to-day basis. NWP focuses on taking current observations of weather and processing them using computer models to forecast the future state of weather for the next few days.

An accurate prediction of the large-scale flow pattern that brings warm and moist air to the Svalbard archipelago is instrumental for early-warning of the risk of these events to occur. This type of large-scale patterns need to be captured in (*sub)-seasonal climate predictions*[L] (next weeks and months). As illustrated in Fig.7, a week before the event the sub-seasonal prediction clearly showed an air mass stretching from Iceland to the Russian Arctic, giving the south-westerly flow east of Greenland (Fig.7, left). Most of the structure was also captured two weeks in advance (Fig.7, middle), although in this case the pattern resembled more a negative *North Atlantic Oscillation (NAO)*[M] than a Scandinavian blocking pattern. The node over Iceland was also captured three weeks in advance, although the extension to the North did not appear in this case (Fig.7, right).

Sub-seasonal forecasts are likely to capture large-scale patterns (lasting more than a week). Such forecasts have *skill*[N] predicting Scandinavian blocking 9-13 days in advance (Ferranti et al. 2018).

CONSIDERATIONS

APPLICATE does not directly provide predictions of landslides or slush avalanches, since for that prediction systems need to be coupled with impact models. Such information would require a continued monitoring of different in-situ environmental variables (on soil, permafrost, weather and climate characteristics, among others). Instead, the APPLICATE Project provides the prediction of essential climate variables (temperature and precipitation), indices (EFI for precipitation and temperature) and weather regimes (Scandinavian blocking) that have been related to the risk of occurrence of landslides and slush avalanches in the Svalbard archipelago. These predictions can be related to the likelihood of occurrence of such devastating events, but the relationship is not linear.

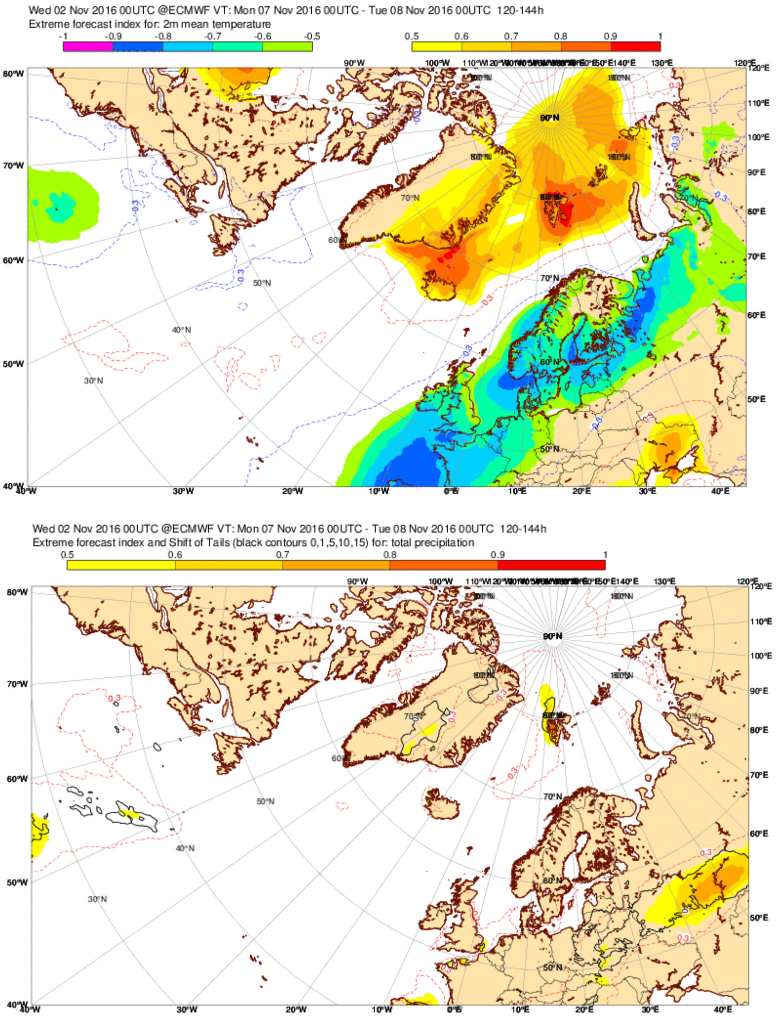

Fig.6. Extreme Forecast Index for 2-meter mean temperature (upper map) and accumulated precipitation (lower map) on 7 November 2016 based on forecasts from 2 November 2016. Red colours indicate the predicted likelihood of very unusual or extreme weather conditions compared to local climate. Source: ECMWF ensemble forecasts. Credit: Linus Magnusson, ECMWF.

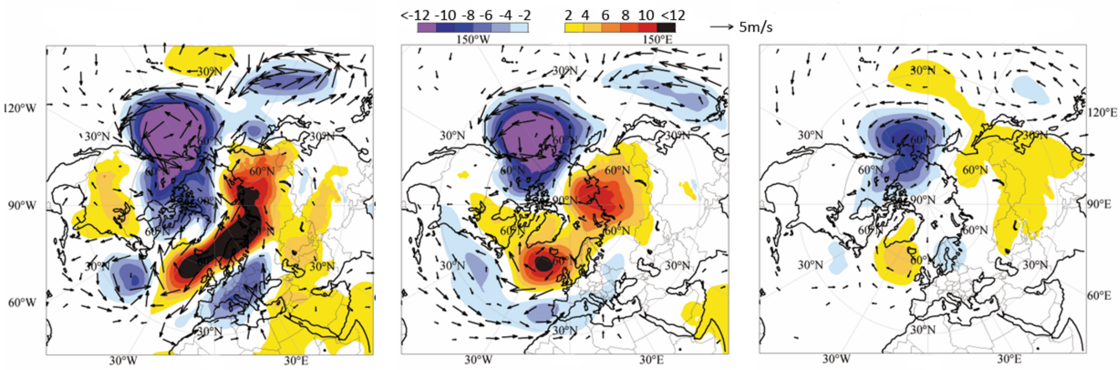

Fig.7. Mean sea level pressure anomalies in hPa (shaded areas) and surface wind anomalies in m/s (arrows) for the week of the 3-7 November 2016 predicted one week (left), two weeks (middle) and three weeks (right) in advance. Red colours indicate higher pressures for the rainfall event in November 2016 as compared to the period 1996-2015. Source: ECMWF extended-range forecasts. Credit: Linus Magnusson, ECMWF.

Improvements in the prediction of precipitation amount and phase provided by high-resolution model topographies are promising since there is empirical evidence that a rain intensity of 2mm/hour is a critical value for the release of the active layer detachment slides, debris flows and mudflows in the permafrost around Longyearbyen (Christiansen et al. 2016).

If the frequency of Scandinavian blockings should change in the future, severe precipitation events related to this weather pattern will change as well. Actually, daily precipitation extremes are predicted to increase in the future over mid- and high-latitudes (AMAP 2017). In addition, long term climate projections for Svalbard show the possibility of an increase in the frequency and intensity of extreme precipitation events (Hannsen-Bauer et al. 2019).

K

Extreme Forecast Index (EFI): Index highlighting regions that are forecasted to have potentially anomalous, extreme or severe weather conditions compared to local climate (e.g. heavy precipitation, strong winds, heavy snowfall, extreme temperatures, etc.). EFI values higher than 0.8 indicate a likely very unusual or extreme weather. Check ECMWF website for more information.

L

Sub-seasonal and seasonal climate predictions: Probabilistic climate predictions for the next weeks (sub-seasonal) up to 3 months (seasonal) into the future. Check the Sub-seasonal to seasonal prediction project (S2S) for more information.

M

North Atlantic Oscillation (NAO): Major circulation pattern influencing the weather and climate from Eastern North America to Europe. The negative NAO phase tends to steer depressions towards Southern Europe bringing wetter conditions while Northern Europe tends to be drier.

N

Skill: Quality of a prediction based on its performance in the past that provides information on the usability of that particular prediction for future decision-making.

Consequently, erosion and sediment transport are predicted to increase and avalanches and landslides will become more frequent, while near-surface permafrost is projected to thaw in coastal and low altitude areas (for the high emission scenario). Having advanced predictive capabilities, thus, would be highly desirable to ensure the preparedness of the public in a hotspot of rapidly changing climate.

STAKEHOLDERS

Potential applications of the results from this case study are envisaged in the areas of **civil protection and preparedness** (e.g. avalanche warnings, preparation for possible perils, adaptation measures implemented as response to a past event), **urban planning** (e.g. delimitation of risk zones for landslides and avalanches), **wildlife protection** (e.g. prediction of rain-on-snow events resulting in ice-encrusted pastures and reindeer mass starvation), **agriculture** (e.g. ice-encrusted crops and mould formation), **tourism** (e.g. planning of leisure activities like snow-mobile driving, dog-sledging, hiking, etc. and account for activity changes or cancellations) or **health** (e.g. psychological challenges coming with climate changes).

OUTCOMES FROM THE CASE STUDY

Reliable weather and climate forecasts are crucial to protect lives and properties in the context of an increasingly warmer and rainier Arctic. However, forecasting systems generally show lower forecast skill at high latitudes compared to other regions. Forecasting high-impact weather events in the Arctic (such as the rain-on-frozen ground event described in this case study) is especially challenging due to various sources of uncertainty that include observation gaps and errors as well as uncertainties in the model parameterisations of small-scale processes, including challenges unique to the Arctic.

With this case study, the contribution of the APPLICATE project is twofold:

- **Contribute to understanding linkages between the Arctic and mid-latitudes.** Scandinavian blocking events have their origin in mid-latitude dynamical processes that have an impact on Arctic socio-economic aspects.
- **Illustrate how enhanced weather and climate information can make a difference for the preparedness of local populations to deal with events that can be catastrophic.** Timely sub-seasonal predictions of the occurrence of large scale weather patterns provided by the project can be used as early-warning for the potential occurrence of rain-on-snow or rain-on-frozen ground events in Svalbard related to potential risks of landslide and avalanche. Warnings could be confirmed a few days prior to the event through EFI predictions of temperature and precipitation that, together with short-range high-resolution forecasts able to capture topography, can support decision-making of civil protection and rescue and preparedness teams.

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