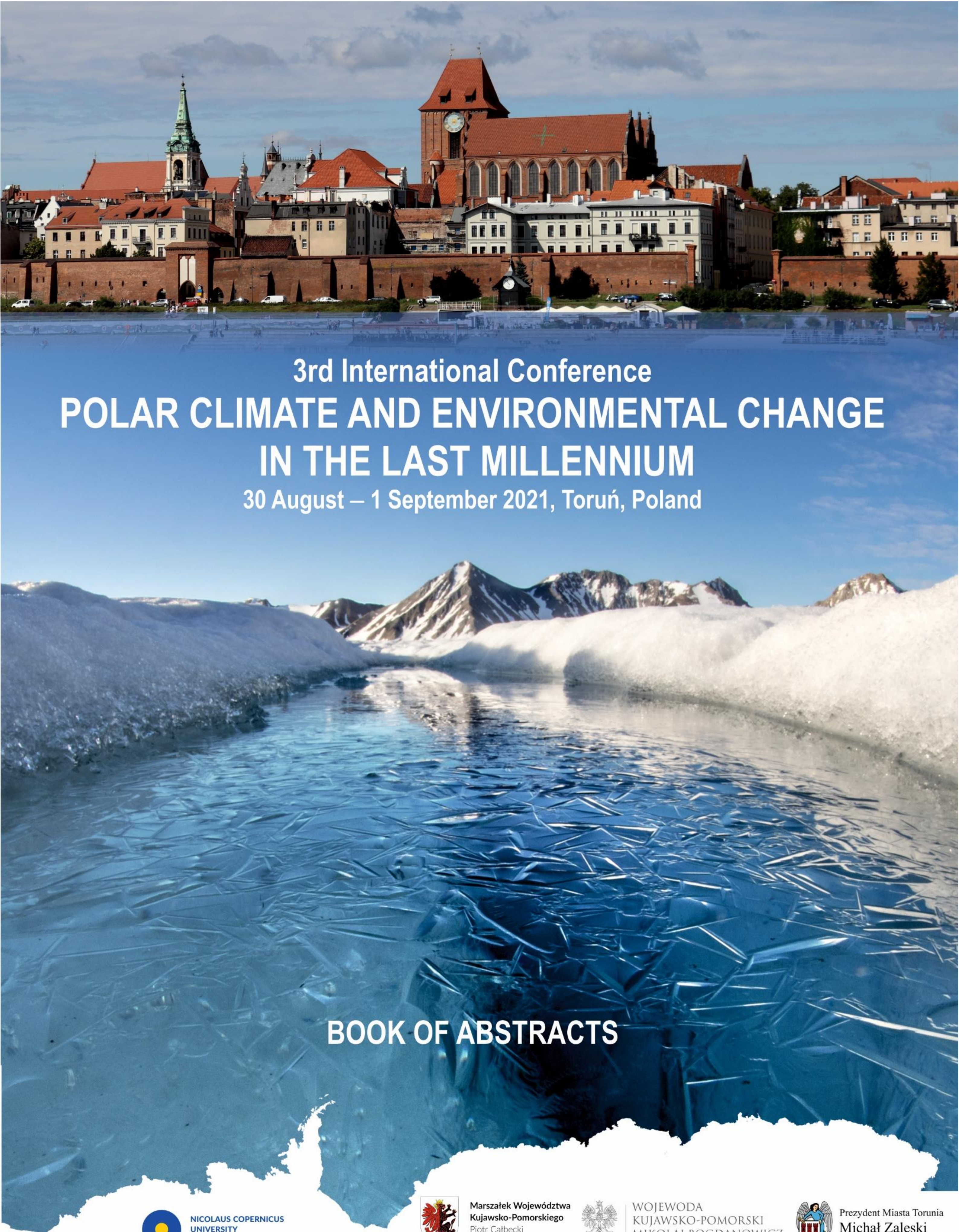

3rd International Conference

POLAR CLIMATE AND ENVIRONMENTAL CHANGE IN THE LAST MILLENNIUM

30 August – 1 September 2021, Toruń, Poland

BOOK OF ABSTRACTS

NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Marszałek Województwa Kujawsko-Pomorskiego
Piotr Całbecki

WOJEWODA KUJAWSKO-POMORSKI
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Ministry of Education and Science

NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ
Faculty of Earth Sciences and Spatial Management

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3rd International Conference

POLAR CLIMATE AND ENVIRONMENTAL CHANGE IN THE LAST MILLENNIUM

August 30 - September 1, 2021
Toruń, Poland

PROGRAM AND BOOK OF ABSTRACTS

Editors: Andrzej Araźny, Rajmund Przybylak

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Faculty of Earth Sciences and Spatial Management
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Lwowska 1, 87-100 Toruń, Poland

2021

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- Prof. Dr. **Klaus Dethloff**, Alfred Wegener Institute, Atmospheric Physics Section, Potsdam, Germany. Research interests: *climate change, atmospheric physics, meteorology, climate modeling, climatology, atmospheric modeling, atmospheric aerosols, sea ice*
- Prof. Dr. **Jari Haapala**, Finnish Meteorological Institute, Marine Research Unit, Helsinki, Finland. Research interests: *physical oceanography; climate variability and change; development of numerical models and sea ice dynamics research*
- Dr. **Ketil Isaksen**, Norwegian Meteorological Institute, Division for Model and Climate Analysis, Oslo, Norway. Research interests: *climate change; climate variability; permafrost and mountain climate; soil temperature and permafrost propagation; impact of climate change and extreme weather on permafrost, snow, natural hazards and society*
- Dr. **Willem G.M. van der Bilt**, University of Bergen, Department of Earth Science, Norway. Research interests: *paleoclimate, Holocene, biomarkers, sedimentology, limnology, Arctic, Southern Ocean*
- Prof. Dr. **Wiesław Ziaja**, Jagiellonian University, Faculty of Geography and Geology, Department of Physical Geography, Kraków, Poland. Research interests: *geocomplexes and geosystems; diversity and functioning of the natural environment; ecology and landscape protection; geographical determinants of nature protection*

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SESSION 1: MODELLING OF POLAR CLIMATE and MARINE AND LAND ECOSYSTEMS

Chair: Joanna Wibig

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Arctic climate puzzle: The role of observations, weather forecast- and climate models

Klaus Dethloff[1], Dörthe Handorf[1], Ralf Jaiser[1], Raphael Köhler[1]
[1] Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany

The Arctic climate system is changing rapidly, but quantification of the driving atmospheric and oceanic processes within the Arctic amplification puzzle is limited, because weather- and climate models do not work well in the Arctic. The 2019/20 MOSAiC project and other in situ observations and process studies together with reanalysis data will be used to improve understanding of the regional and hemispheric consequences of Arctic sea ice loss and to improve numerical weather prediction models and climate models. The influence of Arctic sea ice decrease, stratospheric ozone chemistry, and gravity wave parameterizations in relation to evolving baroclinic weather systems, their interaction with planetary waves in the troposphere, and tropo-stratospheric feedbacks are analyzed in climate models. Results from regional ensemble simulations with a coupled Arctic climate system model and the role of internally generated sea ice variability will be discussed. Additional Arctic radiosondes in strongly baroclinic regions can improve cyclone forecasts for large-scale atmospheric flow situations in weather prediction models.

Land loss and sea transgression due to recession of Arctic glaciers under contemporary climate warming

Wiesław Ziaja
Jagiellonian University in Cracow, Poland

Recession of the tidewater glaciers leads to the sea transgression and land loss in many Arctic coasts due to decline of glacial ice masses (lowest parts of the glaciers) below the sea level. The sea level rise due to melting of glaciers above this level, thermal expansion of ocean water, etc., is too small (yet?) to be the first factor of the land loss in Arctic. Transformations of the tidewater glaciers have led to the following spectacular changes in the landscape and topography – thus in geography – of the Arctic coasts: (1) changing mountain valleys filled with glaciers into new fjords or other bays, and lengthening or widening old fjords or other bays, (2) changing fragments of the glaciated coasts into new straits and islands. The former change was described widely in different parts of Arctic, and in this lecture, will be shown in the SE Spitsbergen (where the author carried out his research recently). The latter change was described by a small number of authors, and the first study on it covering all the Arctic was published by Ziaja and Ostafin in 2019. Analysis of maps and satellite images of the Arctic coasts has been a basic method of recognizing these changes. Ziaja and Ostafin revealed that a total of 34 new islands (each 0.5 km^2 or above) have appeared due to recession of Arctic glaciers under climate warming since the 1960s, and a few more new islands appeared in this period were found afterwards. The new islands appeared in the coastal areas where bedrock elevations above sea level are surrounded by depressions below this level, filled (at least from the landside) with glaciers. Their recession led to flooding of the depressions by sea water, thus creating new straits which separate the new islands from the mainland. Until now, such new islands appeared only in Greenland and the European Arctic (Franz Josef Land, Svalbard, Novaya Zemlya). Additional straits and islands are currently at the stage of formation and will continue to form in the case of further warming or stabilization of the current climate conditions. Ecosystems of the new islands must accommodate to new environmental conditions, and their biodiversity increases. In the new straits, replacing the glacial ice with sea water is surely favorable for life expansion. The new straits have already shortened some sea routes, and some Arctic sea-ways will shorten with continued climate warming (especially a potential new strait across today's southern Spitsbergen).

Reconstruction of the hydrological processes in four High Arctic catchments (SW Spitsbergen)

Marzena Osuch[1], Dariusz Ignatiuk[2], Elżbieta Łepkowska[2], Krzysztof Migała[3]

[1] Institute of Geophysics PAS, Poland; [2] University of Silesia in Katowice, Poland; [3] University of Wrocław, Poland

The study focuses on the reconstruction of hydrological processes in four High Arctic catchments (Fuglebekken, Ariebekken, Bratteggbekken, and Breelva) located in the vicinity of the Polish Polar Station Hornsund. For this purpose, a set of different rainfall-runoff models were tested. The models were calibrated and validated using archival in-situ and remote observations. Past hydrological conditions in these catchments were simulated in the period 1979-2020 with help of models that gave satisfactory results for all catchments using measured air temperature and precipitation from the PPS Hornsund. The outcomes indicated statistically significant increases in runoff estimated for all catchments. In addition, changes in the flow regime were analysed. The results showed similar changes in all catchments that include an earlier occurrence of snowmelt driven floods, large increases in autumn flows, prolongation of the hydrologically active season (starts earlier and lasts longer), decrease in discharges in the second part of June and the first part of August (except Breelva). The flow regime has changed from snowmelt dominated to the bi-modal with two peaks (one peak in July/August and the second in September). There are also differences in the results due to different areas covered by glaciers in the analysed catchments. The slope of the estimated trends depends on the amount of glacierized area. The larger the glacierized area is the larger changes in the flows.

Acknowledgements. This study was supported by the Polish National Science Centre (grant no. 2017/27/B/ST10/01269).

Environmental coastal monitoring adjacent to the Arctic Gates offshore oil terminal

Olga Kulikova [1], Anastasiia Karnaeva [1, 2], Elena Mazlova [1], Yana Blinovskaya [3]
[1] National University of Oil and Gas (Gubkin University), Russia; [2] Frumkin Institute of Physical chemistry and Electrochemistry RAS, Russia); [3] Far Eastern Federal University, Russia

The Cape Kamenny territory (Ob Gulf, Russian Arctic zone) is exposed to various potential sources of pollution, including emissions from infrastructure facilities of the Arctic Gates offshore oil terminal, a loading port, a tank field, a helipad, a landfill, and a village. To monitor annual dynamics of environmental pollution of the coastal area, samples from lakes, water accumulations in floodplains, coastal water, bottom sediments, sand of the littoral zone of the Ob Gulf, and samples of *Erióphorum* plants were taken. Selected samples were analyzed for the content of the main pollutants: petroleum hydrocarbons (TPH), PCBs, heavy metals, metalloid (As), and microplastics.

It was observed that TPH concentrations in water sampled from the lake located behind the landfill and the tank field, exceeded the maximum permissible concentration of 0,05 mg/L (for fishery use) by 3.8. Comparative analysis of TPH concentrations in surface water found out in 2018 and 2019, showed a stable biannual TPH-contamination dynamic. Oil-contamination of soil was established at 0.39 – 1.51 g/kg level, revealing the presence of oil-contaminated spots nearby petroleum storage units of the tank field and the helipad.

However, V (0.03±0.001 mg/L), Cr (0.07±0.0002 mg/L), As (0.01±0.001 mg/L), and Mo (up to 0.64±0,1 mg/L) were indicated as a main surface water pollutants among heavy metals. The coastal water analysis showed a lower Mo content

Moreover, during the expedition in August 2018, the lake located behind the landfill and the tank farm was characterized by alkaline pH of 9.5±0.4, being abnormally high for natural waters of the Yamal peninsula. Presumably, the filtration waters of the landfill change water pH towards a weakly alkaline and alkaline reaction. During the expedition in 2019, the measured pH values were set within 8.0±0.1. This result can be correlated to an absence of atmospheric precipitation during the expedition period in July 2019 compared to the previous expedition with daily rainfalls, which, in turn, indirectly points out the role of filtration effluents from the landfill.

IR-analysis of littoral sand samples showed the presence of microplastics such as sodium alginate ($C_5H_7O_4COONa$), acrylic polymer, dioctyl adipate, and modified polyamide (TETA).

Therefore, the annual monitoring of environmental pollution is recommended for the highly exploited Arctic coastal area.

SESSION 2: GLACIERS AND SEA-ICE HISTORY

Chair: Wojciech Dobiński

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Arctic sea ice changes - from quiet to more dynamical regime

Jari Haapala
Finnish Meteorological Institute, Helsinki, Finland

Mass balance of the Arctic Sea ice depends on thermodynamical and dynamical factors. Thermodynamical and mechanical sea ice state variables are strongly coupled, but the strength of coupling varies in daily, seasonal and climate time scales. When ice pack is thick, solid and compact, this coupling is strong and large areas of pack ice are mechanically connected. In these circumstances, internal stress of pack ice is accumulating and reducing differences in ice motion. In these conditions drift speed of Arctic Sea decreases, age of ice increases and total mass of ice pack increases. On a contrary, thinner ice pack which includes cracks, leads or larger open water areas is in turn mechanically weakly connected, exhibits larger variations in motions in shorter time and length scales, drifts with higher speed and exhibits shorter residence time in the Arctic. In this talk, importance of ice dynamics on sea ice mass balance is reviewed and new findings based the MOSAiC campaign are discussed.

Recession of Icelandic glaciers over the last century: towards a machine learning technique for assessment

Thomas Y. Chen
Academy for Mathematics, Science and Engineering, Rockaway, U.S.A

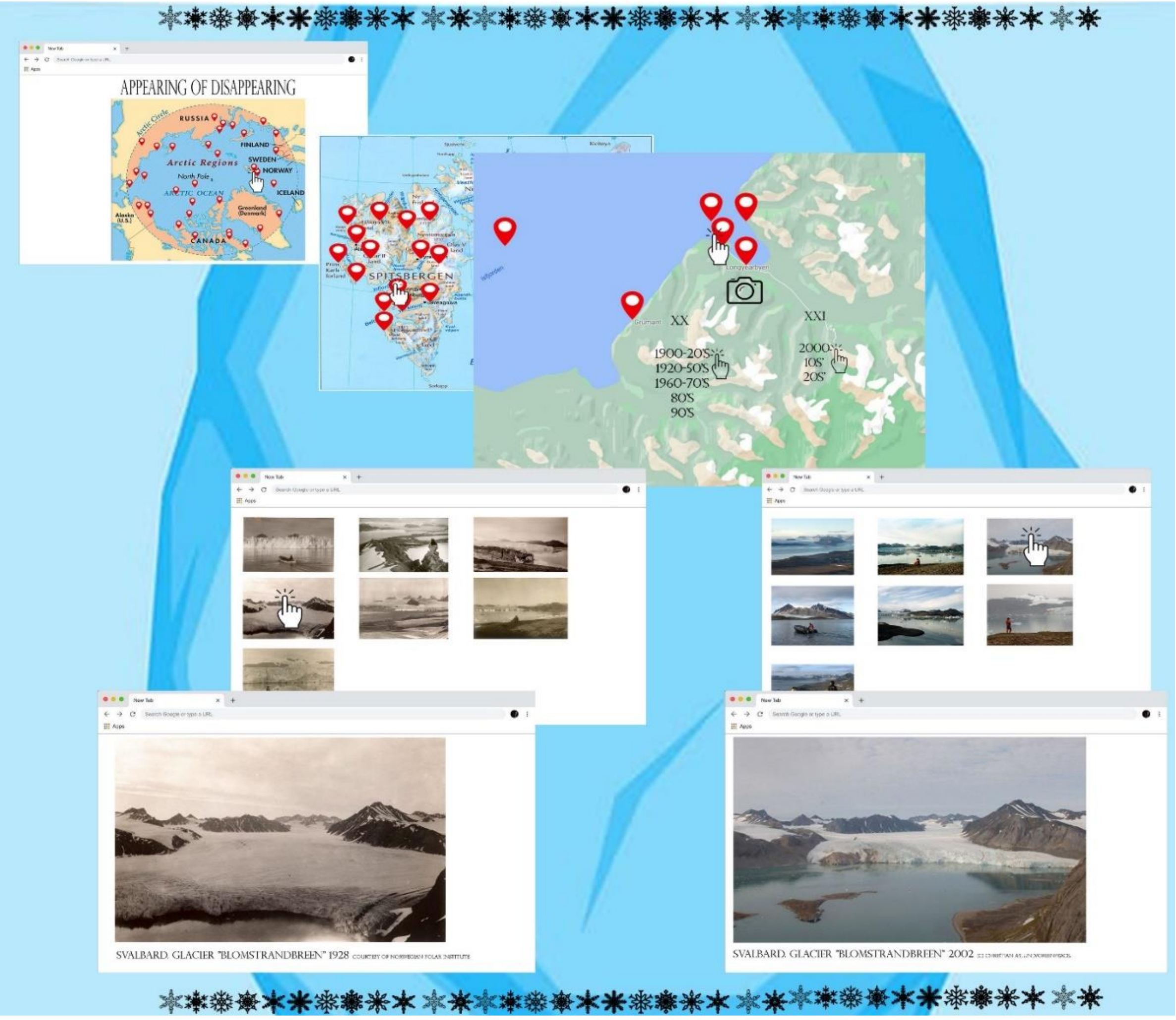
Icelandic glaciers have receded significantly over the last one hundred years in large part due to anthropogenic climate change. For example, from 2000 to 2019, 750 square kilometers, or 7 percent of the Icelandic glacial surface, were lost. In order to further understand the impacts of global warming on the Arctic and the world at large, glacial change is an important geophysical parameter to study. In this work, we propose a novel automated machine learning-driven technique for the assessment of the recession of Icelandic glaciers over the last century. We utilize satellite imagery and harness transfer learning for change detection across time scales. We propose a convolutional neural network, of the ResNet architecture, to be trained on this multitemporal data. The primary aim is to provide a more comprehensive, computational methodology for the assessment of the visible impacts of climate change on the island via Earth observation.

One Arctic-thousand cameras

Anastasia Deykka
Association of Polar Early Career Scientists

The core is: to unite - to collaborate - to be aware. My experience in the world of photography is adapted to the needs of monitoring global warming in the Arctic. Through national official photo archives and private photos to scientific photo documentations, I intend to make the younger generations aware of how dramatic and rapid climate change, especially with snow peaks, mountain lagoons and glaciers.

Everyone today has a story; the world's an archive. I invite people, whose hearts are melting together with the Arctic ice, to share their evidence of global climate change, to contribute for future generations, about what would probably be lost forever soon. Not many people can speak in the scientific way, but everyone can understand the message of photography. To hear "Before we had permanent snow here" from indigenous Arctic habitants means little for millennials. Neither, scientific data or satellite maps. But photography remains unique and the most informative, dogmatic language.



SVALBARD. GLACIER "BLOMSTRANDBREEN" 1928 COURTESY OF NORWEGIAN POLAR INSTITUTE

SVALBARD. GLACIER "BLOMSTRANDBREEN" 2002

What: Constantly updated Web archive (social network analog) of photo materials related to Arctic

Why: The Archive exists to keep things safe, but not secret. Archive is the bridge from the past to the future. Every contribution in the “Appearing of disappearing” project makes better understanding of the Arctic future

Who: Everyone is welcome to contribute personal photos related to Arctic

How: Voluntary contribution of Arctic related materials with proven date and time track to represent present and the future. Plus collaboration with government and private photo archives to reflect the past

Innovation: Amateur and spontaneous photography will speak scientific data and at the best help to build climate changing trends

SESSION 3: DYNAMIC OF PERMAFROST

Chair: Marzena Osuch

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Past and recent changes in permafrost characteristics and ground temperatures in the Arctic

Ketil Isaksen
Norwegian Meteorological Institute, Norway

Permafrost refers to Earth materials that remain at or below 0°C for two years or longer. Overlying the permafrost is the active layer, which thaws and refreezes annually. Permafrost underlies extensive regions of the high-latitude landscape. Permafrost temperatures have risen during the last decades in all areas of the Arctic lowlands. Recently, considerable attention has also been paid to rising ground temperatures in mountain permafrost and how areas with steep and cold terrain may respond to global warming. Permafrost, especially where it contains large volumes of ground ice, can play a critical role in the stability of Arctic and mountain landscapes. Permafrost warming, active layer thickening, and ground ice melt cause changes in hydrology, surface topography and landscape stability, having implications for integrity of infrastructure and ecosystems. Changes in permafrost conditions can also affect the rate of release of CO2 and CH4 to the atmosphere, with the potential to accelerate global warming.

Permafrost monitoring sites across the Arctic have been recording ground temperature for up to five decades, providing critical data on changes in permafrost stability. Observed changes in active layer thickness relate to shorter-term fluctuations in climate. The increase in permafrost temperatures observed since the 1980s is generally greater in the relatively colder permafrost at higher latitudes, where the largest increase in air temperature is observed. Permafrost temperature trends also show local variability, due to other important influences such as snow depth, density, and timing (snow-on/snow-off date and duration); vegetation characteristics; and soil moisture. Observed changes in permafrost temperatures and permafrost characteristics through 2020 are presented for sites throughout the Arctic, with special focus on existing and new permafrost monitoring sites on Svalbard.

Thermal state of mountain permafrost in Northern Transbaikalia (Russia)

Irina Chesnokova[1], Dmitri Sergeev[2]
[1] Institute of Water Problems RAS, Moscow, Russia; [2] Sergeev Institute of Environmental Geoscience RAS, Moscow, Russia

Four sites where geo-temperature observations are conducted are analyzed for the time interval 2006-2019. The data on the temperature state of permafrost are supplemented by microclimatic observations and observations of soil moisture and air humidity in the inter-pore space in block-debris slopes (kurums).These site are located in different altitude from 700 to 1640 m.

Belenkiy Site is located at the first river terrace that is conjugated with the slope fan. The last decade the permafrost demonstrates the permanent cooling from -2.5 to -3.3°C. This dynamic is opposite to climate warming. Zagryazkin Pit and Borehole #37 are located in the low part of the slope at the upper part of Klyukvenniy River. The kurums deposits are underlayed by coarse debris moraine. The permafrost under kurums warmed from -9.9 to -8.4°C during last decade. Borehole #38 is located at flat watershed divide with coarse debris eluvium. Permafrost here warmed from 1987 up to 0.9°C. The last decade the permafrost temperature follows quickly to climate oscillation because low water content of the rock. Ushelistiy Site is located at the dividing saddle is located between Ushelistiy Creek and Nijniy Ingamakit River on Ridge Udokan. Here the permafrost in loamy sands demonstrates a warming tendency from -5.7 to -5.1°C at their table.

Over the past ten years, against the background of a gradual warming and desiccation of the climate, the permafrost of the intermountain basins and piedmont fans gradually becomes colder. On the contrary, mountain permafrost at different altitude shows a noticeable warming. It was found also that the average annual air temperature changes synchronously at different altitudes, following changes in the regional climate.

Permafrost and active layer: criteria for a correct understanding of both

Wojciech Dobiński
University of Silesia in Katowice, Poland

In the permafrost environment, the variability of soil temperature occurs in two different but complementary geological layers: the active layer (AL) and the permafrost layer. The AL is not part of the permafrost as it thaws seasonally. Nevertheless, in both of these layers, the temperature is subject to seasonal variability. In the AL, the temperature values (°C) are both positive and negative, while in the permafrost layer, the temperature variation takes place only in the negative temperature range. This changeability extends down to zero annual amplitude (ZAA), which is usually inside the permafrost layer and sometimes below, where the permafrost is thinner than the depth of the seasonal temperature variation.

The AL is commonly defined as a medium in which the water phase changes seasonally: it freezes in winter and thaws in summer, and is located above the permafrost. Therefore, its activity is based on seasonal thawing and freezing of water contained in the ground, which is inconsistent with the definition of permafrost, which is defined as the thermal state of the medium: rock, soil etc. The fact that it does not have to be frozen results from the term *cryotic state*, which means that medium remaining at negative temperature is not frozen because of mineralization or water pressure.

These findings show that the definition of the AL and of permafrost are not consistent with each other. Each of them is based on a different physical dependence. The AL is based on the water phase change, permafrost on the temperature of the medium. Compatibility of the definition of the AL and permafrost is possible when both terms are defined uniformly, i.e. either based on the criterion of temperature or the phase change. Because the second criterion automatically eliminates the *cryotic state* as an alternative form of permafrost, the only solution is the recognition of the thermal state as the only correct solution, both in terms of permafrost and the AL.

The resolution of this issue is important for the correct understanding and analogical treatment of both permafrost and the AL, because definitions based on various dependencies may lead to misunderstandings and errors, especially with regard to the essence of the research: what is in fact the subject of the research: thing or state? this applies to all three media associated with the active layer and permafrost: soil, water and ice ranging from 0 to 100% of the volume in the medium.

SESSION 4: RECONSTRUCTION OF POLAR CLIMATE AND ENVIRONMENT

Chair: Wiesław Ziaja

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Was Common Era glacier expansion in the Arctic Atlantic region triggered by unforced atmospheric cooling?

Willem G.M. van der Bilt[1], Andreas Born[2], Kristian Haaga[2]
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The timing and causes of glacier growth in the Arctic Atlantic region during the last millennium remain elusive. There is mounting evidence of advances that predate the classical Little Ice Age (1250-1850 CE); this challenges the view that 13th century volcanic eruptions triggered change by spurring sea-ice expansion. Recent climate model simulations indicate this response does not require external forcing under contemporaneous pre-Industrial boundary conditions. Our work reconciles these new insights by combining regional proxy evidence of glacier and sea-ice change with a climate model experiment. Collated recently published reconstructions demonstrate that regional climate shifted towards a colder mean state around 650-950 CE, a period marked by minimal radiative forcing. Unforced simulations reproduce the time-transgressive evolution of this response, which emerged east of Greenland and progressed eastwards towards Svalbard. The inferred pattern is associated with sea-ice feedbacks, triggered by stochastic (spontaneous) atmospheric cooling. We argue that this mechanism may help explain the timing and pattern of Late Holocene glacier growth in the North Atlantic Arctic region.

The past climate of Iceland revisited AD 1400 to 1700

Astrid E.J. Ogilvie [1, 2]

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Boulder, Colorado, U.S.A.

Due to its geographical location at a juncture of cold and warm air and ocean currents, Iceland has an extremely variable climate. In past times it has also been significantly affected by the presence of sea ice off its coasts. This presentation will take a fresh look at the past climate of Iceland for the years ca. 1400 to 1700 based on documentary evidence. Between 1430 and 1560 there are very few contemporary sources. However, circumstantial evidence may suggest a climatic regime that was not unduly harsh during the period ca. 1412 to 1470. A reliable account suggests that the 1560s were very cold with much sea ice while the 1570s were mild. Several extremely interesting accounts of the climate for the period of the late sixteenth to early seventeenth century were written by a number of learned Icelanders These suggest a cold climate during these decades. A cooling trend may be seen around the beginning and end of the seventeenth century. However, these periods are separated by a mild period from ca. 1640 to 1670. It is interesting to note that this coincides with a cold period in central Europe that is often regarded as being at the height of the so-called “Little Ice Age”. This temperature pattern in Iceland correlates well with the sea-ice variations including a period with very little ice during ca. 1640 to ca. 1680. As well as outlining the available data, the presentation will discuss the local observers whose careful and detailed accounts provide present-day scientists and scholars with extremely valuable information.

A few remarks on the dynamics of contemporary climate conditions in Svalbard

Krzysztof Migała[1], Marzena Osuch[2], Dariusz Ignatiuk[3], Elżbieta Łepkowska[3], Tomasz Wawrzyniak[2], Piotr Owczarek[1]
[1] University of Wrocław, Poland; [2] Institute of Geophysics PAS, Poland; [3] University of Silesia in Katowice, Poland

On the basis of the long-term climatological data from the Polish Polar Station at Hornsund Fjord, SW Spitsbergen (1979 - 2019), we undertook an analysis of selected climatological indices, followed by an attempt to assess the scale of impact on the local environment. The indices were selected based on the recommendations of the European Climate Assessment & Dataset (ECA&D, 2013) and in accordance with the WMO recommendations in relation to drought indices (WMO, 2016). Phyto-bioclimatic indices (sum of temperatures, growing degree-days, length of growing season) were supplemented with indices with the thermal threshold of daily mean air temperature of +2.5°C. Some of the temperature and precipitation indices were calculated based on percentiles of these variables calculated for a population of daily values from the 1981-2010 climate standard. In addition, we paid attention to the number of melting days (NMD days with Tmax ≥ 0°C)~~,~~ which can be treated as a simple index of snow cover formation and snow avalanches as well as the winter element of the glacier mass balance and the initial conditions of active development of the permafrost layer, solifluction and geohazards of slope mass movement. Most indices based on temperature and precipitation show an increasing trend, except for a few that show a decreasing trend as a result of warming. These include: HDD15.5 (heating degree-days expressing the energy needed to heat a building), ID (No. of ice days), Tavg10p (No. of cold days), CD (No. of cold & dry days), CW (No of cold & wet days) and drought indices for some months.

A greater share of both cyclonal and anticyclonal circulation from the S+SW sector, forcing the advection of warm air masses from the south, was decisive in terms of the trends of change in comparison with the long-term mean. Both extreme precipitation and drought events depend on anomalies of geopotential height of 500hPa and of precipitable water determined by the baric field over the North Atlantic.

Trends in change of climatic variables have an impact on the dynamics of local geoecosystems. They produce faster ablation and retreat of the glaciers, degradation of permafrost, intensification of the hydrological cycle in glacier-filled and glacier-free basins and changes in the condition and growth of tundra vegetation.

Calls to action: Indigenous community-led climate change resiliency in Canadian Arctic

Ranjan Datta
Mount Royal University, Calgary, Canada

The study is responding reconciling Indigenous climate change resiliency in the Canadian Arctic**.** We (as an interdisciplinary research team of Indigenous Elders, knowledge-keepers, Indigenous and non-Indigenous scholars) explore, *how recent* climate change *(and interpretation) is challenging to Indigenous food, water sources; and what is at stake in processes such* as consultation, impact assessment, regulatory hearings, approvals (including negotiation of benefits), monitoring? and what reformed processes can build Indigenous community capacity and supports robust decisions? The outcomes will assist policymakers and communities to guide future consultations and impacts assessment guideline and climate change planning initiatives. We will focus on Indigenous understanding of Indigenous philosophies of climate change and the connectivity between climate change and water management and sustainability-related to the interactions and inter-dependencies with health security, Indigenous environmental and cultural value protection.

Objective: *Supporting Indigenous community perspectives on climate change impact management, foods, and water protection*. Contribution: The designing, coordinating, and hosting an interdisciplinary FGDs on the relationship between climate change impacts management and drinking water protection. This Dialogue Session creates new scholarly knowledge about pipeline leak impacts and drinking water protection processes. Objective: *Developing effective and trustful engagement dialogues to build capacity among Indigenous Elders, Knowledge-keepers, and scholars*. Contribution: This objective supports Indigenous perspectives through specific, policy-orientated research that positively impacts their vision and allow them to develop new ways of climate change impacts and drinking water protection. This reveals climate change impacts management and drinking water protection policy and practices in the Arctic. Objective: *Mobilize knowledge and partnership for reconciliation (specifically translate research results into evidence for policy-making) through developing an impact assessment policy guideline*. Contribution: The impact assessment policy guideline shares knowledge and implications of climate change impacts management policy documents local, provincially, and nationally and assist in the articulation and practice of foods and water source protection, as culturally and community informed.

SESSION 5: POLAR CLIMATE CHANGES - INSTRUMENTAL OBSERVATIONS (part 1)

Chair: Krzysztof Migała

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Data rescue and its use for climate research in recent centuries

Stefan Brönnimann
University of Bern, Switzerland

Long time series of instrumental meteorological measurements have played an important role in climate research. They allow addressing climatic changes in the past and putting recent climate into a historical context. There are only very few long series that are suitable for that purpose; the numerous shorter records rarely were in the focus. Recent advances in numerical techniques, including data assimilation, machine learning and others, and a shift in interest from the seasonal climate state towards the process scale now change this focus. Weather reconstructions provide additional information to climate reconstructions, and they can make use also of shorter records and also of non-instrumental, documentary data. A recent inventory of early instrumental records brought to light thousands of pre-industrial records, many of which are now digitized. While the Arctic remains a poorly covered region prior to the 20th century, efforts have targeted specifically the Arctic. Moreover, documentary data, including ice phenology, can be used for climate reconstructions. This presentation shows several examples of recent data rescue work and shows how the data can be used in climate research.

A meteorological manuscript for Labrador/Nunatsiavut concerning May 1872-June 1873 found in Moravian Missionary Records

Gaston R. Demarée[1], Thea Olsthoorn[2], Pascal Mailier[1] and Astrid E.J. Ogilvie[3,4]

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A manuscript contained in the Moravian Archives, Bethlehem, USA, entitled *Observations on the weather, giving date, barometer and thermometer readings, etc., Erscheinungsjahr, May 1872 - June 1873* provides daily instrumental meteorological observations and weather observations in a non-specified missionary station of the Moravian Brethren in Labrador. The manuscript is written in German *Kurrentschrift* ("cursive script"). Jean-Alfred Gauthier, astronomer at Geneva, Switzerland, published monthly climatological data from Labrador obtained through cooperation with the Moravian missionaries in Labrador in the late 1860s and 1870s. Comparing the manuscript source with Gautier's monthly values, it was firmly established that the location of the daily meteorological time-series was Hopedale (Hoffenthal).

The daily observations cover the time period from 29 May 1872 to 3 July 1873 with an 8-day break in December 1872. The 3 times daily observations were carried out at 7 am, at noon and in the evening. The instrumental observations consist of atmospheric pressure observations, expressed in (English) inches and tenths of inches while the temperature observations are carried out with a centigrade-scaled thermometer. The non-instrumental observations are: the wind directions on a wind rose with 16 cardinal directions; the strength of the wind; and general meteorological observations including the state of the sky, dry fog, the presence of drift ice in the bay and particular observations on the aurora borealis. Analysis of the daily temperatures showed extreme morning temperatures of -39 °C in the winter and in summer midday temperatures above 20 °C. The wind rose based on a 6 degrees' scale and on the Beaufort scale are drawn and indicate mostly northerly winds. The number of monthly precipitation days (rain, rain and snow, snow) are derived from the weather observation data.

The extended Svalbard Airport temperature series 1898–2020

Øyvind Nordli[1], Przemysław Wyszyński[2,3], Herdis M. Gjelten[4], Ketil Isaksen[1], Ewa Łupikasza[5], Tadeusz Niedźwiedź [5] Rajmund Przybylak[2,3]

[1] Norwegian Meteorological Institute, Oslo, Norway; Nicolaus Copernicus University in Toruń, Poland; [3]Centre for Climate Change Research, Nicolaus Copernicus University in Toruń, Poland; [4]Norwegian Meteorological Institute, Oslo, Norway; [5]University of Silesia in Katowice, Poland

The Svalbard Airport series from 1898 to present represents one of very few long-term instrumental temperature series from the High Arctic. The series is a composite of daily temperature data from many stations homogenized to be valid for Svalbard Airport for the period 1898-2018 (Nordli et al. 2020). Here an extension of the series to 2020 will be presented. The most pronounced changes in the 122 years record occur during the last three decades. For the present standard normal period, 1991–2020, the number of days warmer than 0°C and 5°C has increased by 25 (21%) and 22 (59%) respectively per year compared to the previous standard normal, 1961–1990. Likewise, comparing the same periods, the number of days colder than -10°C and -20°C has decreased by 42 (32%) and 28 (63%) respectively. During the entire time span of the series, the western Spitsbergen climate has gone through stepwise changes, alternating between cold and warm regimes: 1899-1929 was cold, 1930-1961 warm, 1962-1998 cold, and finally 1999-2020 warm. The latest cold regime was 1.0°C warmer than the first cold one, and the latest warm regime was 2.2°C warmer than the previous warm one. For the whole series, the linear trend for annual means amounts to 0.33°C/decade, which is about 3.5 times higher than the increase of the global mean temperature for the same period. Since 1991, the rate of warming at Svalbard Airport has been 1.4°C/decade.

Acknowledgements. The research work of EŁ, TN, ØN, RP and PW was supported by a grant entitled *Causes of the Early 20th Century Arctic Warming*, funded by the National Science Centre, Poland (grant no. 2015/19/B/ST10/02933). The project stations Akseløya, Svarttangen, Crozierpynten and Sørkappøya were funded by the Polish–Norwegian Research Fund and Norway Grants, AWAKE project PNRF-22-A I-1/07 (Arctic Climate and Environment of the Nordic Seas and the Svalbard–Greenland Area).

Reference. Øyvind Nordli, Przemysław Wyszyński, Herdis M. Gjelten, Ketil Isaksen, Ewa Łupikasza, Tadeusz Niedźwiedź, Rajmund Przybylak, 2020, Revisiting the extended Svalbard Airport monthly temperature series, and the compiled corresponding daily series 1898–2018. Polar Research 39, 3614, DOI: https://doi.org/10.33265/polar.v39.3614.

A novel approach for historical cyclone detection

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This is the first ever work to use whaling data to identify and track historical cyclones in the Southern Ocean. Also, the first to estimate and compare the historical cyclonic frequency with modern cyclonic frequency in the Southern Ocean to the author's knowledge. Two methods have been proposed to capture different aspects of the influence of cyclones on the local weather recorded through meteorological observations. The first method used the relative deepening rate of pressure observations to detect the approach of cyclones towards whaling ships or vice-versa. The number of cyclonic encounters detected is sensitive to the deepening rate threshold applied, and this threshold has been framed taking the climatological conditions of the region under investigation into account. The monthly number of encounters in the 1930s and 1950s decades could not be compared directly with each other, due to a number of factors such as different Ship-days recorded and distance/area covered for that month. The estimation of cyclones using a linear multi-regression model developed in this study identifies and tracks individual cyclones in space and time. The probability of identifying a cyclone at a given distance from pressure and wind observations on-board a whaling ship is enhanced when multiple ships are close by. On average in each week, two new cyclones and one previously identified cyclone are identified from the whaling dataset. However, the identification and tracking algorithm developed and used in this study is sensitive to the definition of cyclones and the translational speed assumed; this is, in turn, dependent on the model and the observations used to calibrate the model. Overall, cyclonic frequency over a control area (in the Weddell Sea) appears to have increased significantly from the start of whaling dataset (1930s) to the modern period (2000s); however, more data from the historical period would be required to strengthen this claim.

SESSION 5: POLAR CLIMATE CHANGES - INSTRUMENTAL OBSERVATIONS (part 2)

Chair: Tadeusz Niedźwiedź

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The atmospheric circulation features influence on the repeatability of dangerous weather phenomena in the Western Arctic

Tatiana V. Popova[1], Pavel N. Sviashchennikov [1, 2]
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One of the main problems nowadays is estimating the Climate change in the Arctic. This estimating is based on the analysis of inter-annual variability of surface air temperature. Besides the surface air temperature, the regime of atmospheric circulation is an important characteristic of the Arctic climate. This defines the inter-latitudinal exchange of Warm and Cold air masses and also moisture.

An increase of the dangerous weather phenomena (DWP) frequency in the Arctic region is observed in the context of current warming. In particular, one of the most changeable areas of the Arctic by the weather patterns is the Western Arctic (WA).

The objective of the research is to study the temporal variability of the atmospheric circulation regime and interconnection between circulation regime features and repeatability of the DWP in the WA. The research is done for Cold (October–March) and Warm (April–September) seasons for three climatic periods from the 20th–21st centuries: The Early warming 1920–1950, period of the Cooling 1950–1985 and The Contemporary warming 1985–2020.

The classification of the atmospheric circulation by Girs–Wangenheim for the Atlantic region of the Arctic was used for the research of atmospheric circulation features in the WA. The classification contains the division of the atmospheric processes on the zonal (W–western) and two meridional (E–Eastern and C–Meridional) forms.

The research showed that for all study climatic periods of the 20th–21st centuries the repeatability of the E form of atmospheric circulation prevailed on average. Besides the period of climate Cooling is characterized by the highest repeatability of the number of days with the E form and the lowest repeatability the W form compared to both periods of climate warming. The period of Early warming is characterized by more stable synoptic conditions. The following periods of climate Cooling and Contemporary warming are characterized by the instability of synoptic conditions. In other words, the climate regime is realized as often changeable weather patterns.

The repeatability of the DWP in the WA, on the example of high wind velocity (≥ 15 m/s) at an altitude of 10 m, were the highest in the Central in the period 1920–1950 and in the Southeastern region in 1950–1985. The increase in the instability of synoptic processes and as a result the instability of weather regime, do not contribute to an increase in the repeatability of high wind velocity in the WA.

Acknowledgements. The study was carried out as a part of the project entitled “Causes of the early 20th century Arctic warming” funded by the National Science Centre, Poland (Grant No. 2015/19/B/ST10/02933).

The influence of mesoscale atmospheric circulation on Spitsbergen air temperature in periods of Arctic warming and cooling

Ewa B. Łupikasza[1], Tadeusz Niedźwiedź[1]
[1] University of Silesia in Katowice, Poland

The Arctic has experienced step changes in climate conditions, which are still not fully understood. Particularly intriguing was the Early Twentieth-Century Arctic Warming (ETCAW), which occurred prior to anthropogenic interference in the environment. This paper quantitatively assesses the differences in atmospheric circulation patterns during periods of warming and cooling on Spitsbergen with a particular focus on ETCAW. The patterns of atmospheric circulation were taken from the catalog of day-by-day circulation types created for Svalbard. The catalog includes 21 circulation types, assigned to every day between 1920 and 2017. The research focused on winter and autumn, the seasons exhibiting pronounced ETCAW on Spitsbergen. The long-term variability in autumn and winter air temperatures on Spitsbergen significantly depends on the frequency of air advection from clearly defined directions and reveals some seasonal differentiation. Warming was related in autumn to southern and south-eastern advection, in winter to southern advection, and in both cyclonic and anticyclonic conditions. These "warm" types explained up to 21% (September–November) or 25% (December–February) of the variability in air temperature. In winter, cooling was significantly related to anticyclonic type with air advection from the northeast (NEa: 24% of variability): in autumn to cyclonic northern (Nc) and northeastern (NEc) types. During ETCAW, the frequency of warm circulation types was significantly higher, and that of "cold" circulation types significantly lower. No relevant differences in patterns were found between ETCAW and Recent Arctic Warming; however, the frequency of warm and cold types was higher and lower, respectively, during ETCAW.

Acknowledgements. The study was carried out as a part of the project entitled "Causes of the early 20th century Arctic warming" funded by the National Science Centre, Poland (Grant No. 2015/19/B/ST10/02933), and the Research University – Initiative of Excellence: the Emerging Field "Global Environmental Changes", "Climate Change Research Unit" at Nicolaus Copernicus University in Toruń.

Importance of regional indices of atmospheric circulation for periods of warming and cooling in Svalbard during 1920–2018

Ewa B. Łupikasza[1], Tadeusz Niedźwiedź[1], Rajmund Przybylak[2, 3]
[1] University of Silesia in Katowice, Poland; [2] Nicolaus Copernicus University in Toruń, Poland; [3] Nicolaus Copernicus University in Toruń, Centre for Climate Change Research, Poland

The Arctic has experienced prominent climate warming, at the beginning of the 20th century and currently. Comparing the driving mechanism during these periods helps to explain the causes of contemporary climate change. Our study explores the impact of regional circulation on Svalbard's surface air temperature (SAT, 2 m above ground). We used air temperature data from Svalbard Airport, Bjørnøya stations, and three regional circulation indices that describe the frequency of cyclonic conditions, zonal circulation, and meridional circulation. The indices were calculated for four circulation areas with differing circulation conditions and, therefore, may have various impacts on long-term changes in SAT. This was checked for the entire study period (1920–2018), and 30-year sub-periods representing the most prominent climatic events: the early 20th-century Arctic warming (ETCAW), contemporary Arctic warming (CAW), and a cold period between them (CAP).

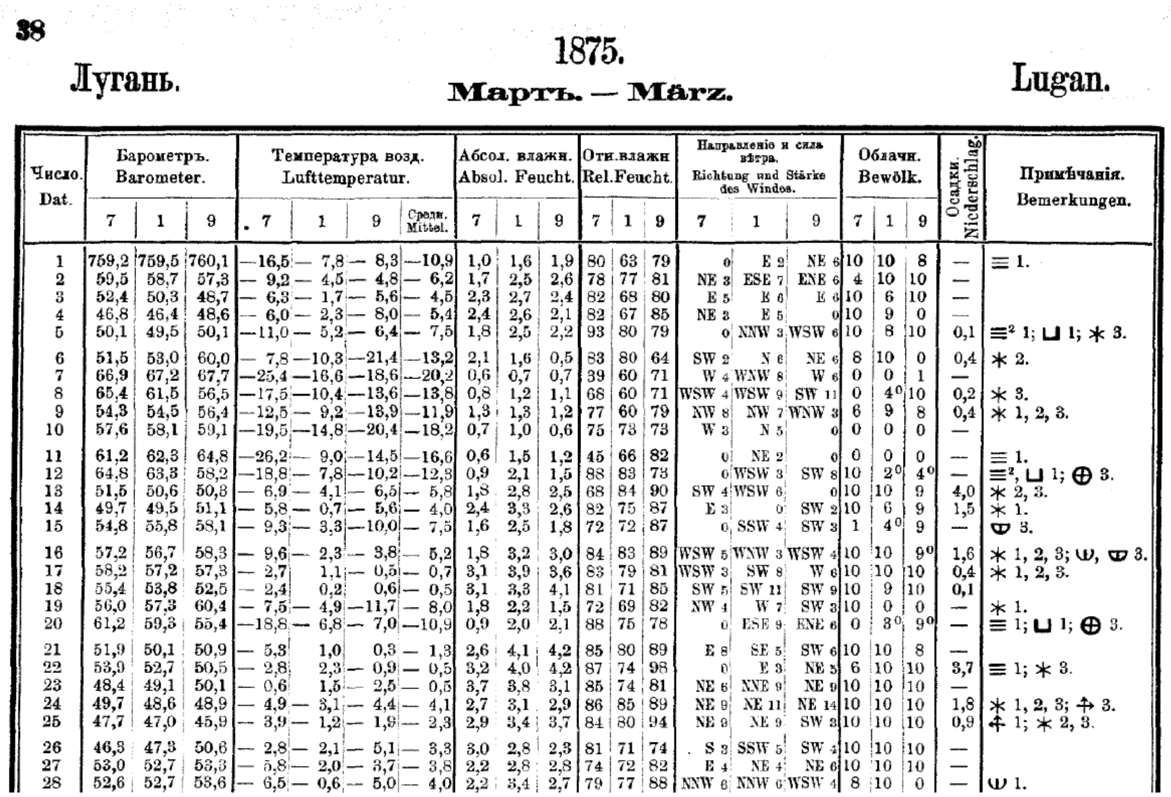
In autumn and winter, the deviations in SAT from the long-term average during warm and cold periods were almost twice as large at Svalbard Airport as at Bjørnøya. In these seasons, the ETCAW was significantly warmer than the subsequent cold period, which was not the case for summer and spring. However, long-term trends in the regional circulation indices were more evident in summer and spring than in autumn and winter. The ETCAW was more related to multi-decadal changes in regional atmospheric circulation than to long-term trends, particularly in SON.

Air temperature was the most strongly influenced by meridional circulation over the eastern circulation areas, with the exception of spring, when air temperature variability was more affected by zonal circulation. The recent warming weakened the relationship between SAT and the indices in summer. We attributed the ETCAW in autumn to a southerly advection of sensible heat. During the same historical period, the impact of the indices was much weaker in winter. In winter during the CAP, there was a higher frequency of northern air advection, particularly over the northern part of the Greenland Sea.

Acknowledgements. The study was carried out as a part of the project entitled “Causes of the early 20th century Arctic warming” funded by the National Science Centre, Poland (Grant No. 2015/19/B/ST10/02933).

SESSION 5: POLAR CLIMATE CHANGES - INSTRUMENTAL OBSERVATIONS (part 3)

Chair: Stefan Brönnimann



38

1875.

Лугань.

Мартъ. — März.

Lugan.

Число. Dat.	Барометръ. Barometer.			Температура возд. Lufttemperatur.				Абсол. влажн. Absol. Feucht.			Отн.влажн Rel.Feucht.			Направленіе и сила вѣтра. Richtung und Stärke des Windes.			Облачн. Bewölk.			Осадки. Niederschlag.	Примѣчанія. Bemerkungen.
	7	1	9	7	1	9	Средн. Mittel.	7	1	9	7	1	9	7	1	9	7	1	9		
1	759,2	759,5	760,1	—16,5	—7,8	—8,3	—10,9	1,0	1,6	1,9	80	63	79	0	E 2	NE 6	10	10	8	—	≡ 1.
2	59,5	58,7	57,3	—9,2	—4,5	—4,8	—6,2	1,7	2,5	2,6	78	77	81	NE 3	ESE 7	ENE 6	4	10	10	—	
3	52,4	50,3	48,7	—6,3	—1,7	—5,6	—4,5	2,3	2,7	2,4	82	68	80	E 5	E 6	E 6	10	6	10	—	
4	46,8	46,4	48,6	—6,0	—2,3	—8,0	—5,4	2,4	2,6	2,1	82	67	85	NE 3	E 5	0	10	9	0	—	
5	50,1	49,5	50,1	—11,0	—5,2	—6,4	—7,5	1,8	2,5	2,2	93	80	79	0	NNW 3	WSW 6	10	8	10	0,1	≡^{2} 1; ⊔ 1; ✱ 3.
6	51,5	53,0	60,0	—7,8	—10,3	—21,4	—13,2	2,1	1,6	0,5	83	80	64	SW 2	N 6	NE 6	8	10	0	0,4	✱ 2.
7	66,9	67,2	67,7	—25,4	—16,6	—18,6	—20,2	0,6	0,7	0,7	39	60	71	W 4	WNW 8	W 6	0	0	1	—	
8	65,4	61,5	56,5	—17,5	—10,4	—13,6	—13,8	0,8	1,2	1,1	68	60	71	WSW 4	WSW 9	SW 11	0	4^0	10	0,2	✱ 3.
9	54,3	54,5	56,4	—12,5	—9,2	—13,9	—11,9	1,3	1,3	1,2	77	60	79	NW 8	NW 7	WNW 3	6	9	8	0,4	✱ 1, 2, 3.
10	57,6	58,1	59,1	—19,5	—14,8	—20,4	—18,2	0,7	1,0	0,6	75	73	73	W 3	N 5	0	0	0	0	—	
11	61,2	62,3	64,8	—26,2	—9,0	—14,5	—16,6	0,6	1,5	1,2	45	66	82	0	NE 2	0	0	0	0	—	≡ 1.
12	64,8	63,3	58,2	—18,8	—7,8	—10,2	—12,3	0,9	2,1	1,5	88	83	73	0	WSW 3	SW 8	10	2^0	4^0	—	≡^{2}, ⊔ 1; ⊕ 3.
13	51,5	50,6	50,3	—6,9	—4,1	—6,5	—5,8	1,8	2,8	2,5	68	84	90	SW 4	WSW 6	0	10	10	9	4,0	✱ 2, 3.
14	49,7	49,5	51,1	—5,8	—0,7	—5,6	—4,0	2,4	3,3	2,6	82	75	87	E 3	0	SW 2	10	6	9	1,5	✱ 1.
15	54,8	55,8	58,1	—9,3	—3,3	—10,0	—7,5	1,6	2,5	1,8	72	72	87	0	SSW 4	SW 3	1	4^0	9	—	Φ 3.
16	57,2	56,7	58,3	—9,6	—2,3	—3,8	—5,2	1,8	3,2	3,0	84	83	89	WSW 5	WNW 3	WSW 4	10	10	9^0	1,6	✱ 1, 2, 3; ɯ, Φ 3.
17	58,2	57,2	57,3	—2,7	1,1	—0,5	—0,7	3,1	3,9	3,6	83	79	81	WSW 3	SW 8	W 6	10	10	10	0,4	✱ 1, 2, 3.
18	55,4	53,8	52,5	—2,4	0,2	0,6	—0,5	3,1	3,3	4,1	81	71	85	SW 5	SW 11	SW 9	10	9	10	0,1	
19	56,0	57,3	60,4	—7,5	—4,9	—11,7	—8,0	1,8	2,2	1,5	72	69	82	NW 4	W 7	SW 3	10	0	0	—	✱ 1.
20	61,2	59,3	55,4	—18,8	—6,8	—7,0	—10,9	0,9	2,0	2,1	88	75	78	0	ESE 9	ENE 6	0	3^0	9^0	—	≡ 1; ⊔ 1; ⊕ 3.
21	51,9	50,1	50,9	—5,3	1,0	0,3	—1,3	2,6	4,1	4,2	85	80	89	E 8	SE 5	SW 6	10	10	8	—	
22	53,9	52,7	50,5	—2,8	2,3	—0,9	—0,5	3,2	4,0	4,2	87	74	98	0	E 3	NE 5	6	10	10	3,7	≡ 1; ✱ 3.
23	48,4	49,1	50,1	—0,6	1,5	—2,5	—0,5	3,7	3,8	3,1	85	74	81	NE 6	NNE 9	NE 9	10	10	10	—	
24	49,7	48,6	48,9	—4,9	—3,1	—4,4	—4,1	2,7	3,1	2,9	86	85	89	NE 9	NE 11	NE 14	10	10	10	1,8	✱ 1, 2, 3; ⇸ 3.
25	47,7	47,0	45,9	—3,9	—1,2	—1,9	—2,3	2,9	3,4	3,7	84	80	94	NE 9	NE 9	SW 3	10	10	10	0,9	⇷ 1; ✱ 2, 3.
26	46,3	47,3	50,6	—2,8	—2,1	—5,1	—3,3	3,0	2,8	2,3	81	71	74	S 3	SSW 5	SW 4	10	10	10	—	
27	53,0	52,7	53,3	—5,8	—2,0	—3,7	—3,8	2,2	2,8	2,8	74	72	82	E 4	NE 4	NE 6	10	10	10	—	
28	52,6	52,7	53,6	—6,5	—0,6	—5,0	—4,0	2,2	3,4	2,7	79	77	88	NNW 6	NNW 6	WSW 4	8	10	0	—	ɯ 1.

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Comparison of Early Twentieth Century Arctic Warming and Contemporary Arctic Warming in the light of daily and sub-daily data

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A review of many studies conducted since the late 1920s reveals that there is still no definite explanation of the main driving mechanisms responsible for the Early Twentieth Century Arctic Warming (ETCAW). Limited knowledge about the climate of this period and some forcings seems to be the main obstacle to reaching the goal. What is required is better knowledge based on data of resolution greater than monthly, i.e., daily and sub-daily.

The main objective of this article is to provide new (or improved) knowledge about surface air temperature (SAT) conditions (including their extreme states) in the Arctic during the ETCAW using available long-term series of daily and sub-daily data taken from five meteorological stations representing large parts of the high Arctic. Four thermal parameters from 10 years were used for this purpose: mean daily air temperature, maximum and minimum daily temperature, and diurnal temperature range. Analysis of rarely investigated aspects of SAT characteristics (e.g.: number of characteristic days; day-to-day temperature variability; and onset, end and duration of thermal seasons) was also conducted. The results were compared with analogical calculations done for data taken from the Contemporary Arctic Warming (CAW) period (2007–16).

The analysed parts of the Arctic showed an increase in mean annual SAT between the ETCAW and the CADW with the greatest magnitude in the Pacific (2.7 °C) and Canadian Arctic (1.9 °C) regions and the smallest (0.2 °C) in the Baffin Bay region. Climate was also more continental, and less stable during the ETCAW than during the CAW.

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Solar radiation in the Arctic during the period 1921–1950

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The period 1921–50 (Early Twentieth Century Warming, ETCW) was characterised by a clear increase in number of actinometrical observations in the Arctic (Przybylak et al. 2021). However, knowledge about the radiation balance and its components for that time is still very limited. That is why large discrepancies exist among estimates of total solar irradiance forcing. We collected all available solar radiation data for the Arctic for the ETCW period, and also for the more contemporary periods. The three components of incoming solar radiation (direct, diffuse and global) are analysed. This new knowledge should allow for more reliable estimation of the magnitude of total solar irradiance forcing.

The availability of solar radiation data for the Arctic for the ETCW period is summarised, and its detailed inventory is presented, including all available metadata. Based on the gathered data series, general solar conditions in the Arctic during the ETCW are described. Average annual global solar radiation in the Russian Arctic during the ETCW were slightly greater than in the period 1964–90 (by about 1–2 Wm^{-2}, and markedly greater than in the period 2001–19 (by about 16 Wm^{-2}). In the period 1920–2019 three phases of solar radiation were distinguished: a brightening phase (1921–50), a stabilisation phase (1951–93) and a dimming phase (after 2000).

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*Reference***.** Przybylak R., Svyashchennikov P.N., Uscka-Kowalkowska J., Wyszyński P., 2021, Solar radiation in the Arctic during the Early Twentieth Century Warming (1921–1950), presenting a compilation of newly available data, Journal of Climate, 33, 21–37, DOI 10.1175/JCLI-D-20-0257.1.

Atmospheric transparency in the Eurasian Arctic during the Early Twentieth Century Arctic Warming

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Atmospheric transparency, after the altitude of the sun above the horizon, is the second largest factor determining the influx of direct solar radiation to the earth's surface under a cloudless sky. Atmospheric transparency depends on water vapour and aerosol content in the air. Since both aerosol and water vapour contents in the air change in time and space, so too the transparency coefficient changes.

The study evaluates atmospheric transparency for selected stations in the Eurasian Arctic (Treurenberg, Bjørnøya, Bukhta Tikhaja, Matochkin Shar, Mys Zhelaniya, Ostrov Uedineniya, Bukhta Tiksi, Mys Shmidta). The measurements at the stations included in the study were performed mainly in the 1930s and 1940s, i.e. during the Early Twentieth Century Arctic Warming. Only at the Treurenberg station were earlier measurements made, in 1899–1900. The annual cycle of atmospheric transparency was examined for all stations, as was the long-term course for selected stations. Long-term measurement data series were available for the Ostrov Uedineniya station in the Kara Sea between Novaya Zemlya and Severnaya Zemlya, and for the Mys Shmidta station, which is the most easterly of all the stations studied.

In the mean annual cycle of atmospheric transparency, the highest values usually occur in autumn, and the lowest in summer. However, in individual years, this pattern is not necessarily observed: both highest and lowest values of mean atmospheric transparency can occur in other seasons. In the long-term course of atmospheric transparency for the Ostrov Uedineniya and Mys Shmidta stations the values were higher in the 1930s than in the 1940s. However, there is no unbroken data series covering all years for any of the stations.

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