## New section of the T-MOSAiC Newsletter

Starting with this newsletter, a special section will be included, with graphical abstracts and small articles focused on a specific theme, edited by the Action Group Chairs. In this edition, **Arctic Transects** is the theme, and our next theme will be **Remote Sensing**. We look forward to your contributions to this and other themes in future newsletters.

## SPECIAL ISSUES

### Special T-MOSAiC Issue of Arctic Science

The T-MOSAiC special issue of *"Arctic Science"* is open for submissions until March 31st 2022. Please visit the T-MOSAiC website for updated information or contact the secretariat: https://www.t-mosaic.com/

### Special T-MOSAiC Issue on Arctic Terrestrial Pollution

The Environmental Pollution Journal (IF: 6.792) is open for submissions. This special issue publication aims to provide original research on Arctic Terrestrial Pollution (including Coastal Areas). This special issue will be edit by João Canário (University of Lisbon, Portugal), Katrin Vorkamp (Aarhus University, Denmark), Mark Mallory (University of Acadia, Canada) and Scott Zolkos (Woods Hole Research Center, USA).

### Special T-MOSAiC Issue on Polar and Alpine Microbiology

The Arctic Microbiomes AG is editing a special issue in journal "Frontiers in Microbiology". On the topic Digitizing Frozen Earth - Revealing Microbial Diversity and Physiology in the Cryobiosphere through ´Omics´ Tools, Volume II", this SI is now open online and ready for submissions until August 14th, 2021. The editors of this SI include Anne Jungblut, Jérôme Comte and Birgit Sattler.

# ACTION GROUP ACTIVITIES

## Arctic Microbiomes AG

### Arctic Microbiomes Workshop

The T-MOSAiC Arctic Microbiomes AG is organizing a workshop.

After a short round table to welcome new members and learn about each participant's research themes, the aim of the workshop will be to update members on ongoing and future activities. This includes:

- ongoing special issue in **Frontiers in Microbiology**
- expected synthesis/review papers
- discussion on outreach activities as well as future collaborative initiatives

The workshop is scheduled on 30 June 2021 on Zoom from 9 am to 12 pm (Eastern Standard Time, North America). This invitation is opened to all T-MOSAiC Arctic Microbiome AG members in addition to those who have expressed interest during ASSW2021. We will forward the details to them. We ask participants to confirm their participation with the AG Chairs so that they can receive the agenda and details by mid-June :
https://www.t-mosaic.com/microbiomes.html

## Permafrost Thaw AG

This AG set up one of the first T-MOSAiC permafrost thaw transects during March 2021 at the Bayelva site (close to Ny-Ålesund, Svalbard). As part of our field work, we started the T-MOSAiC thaw protocol on snow covered ground. Our first data set has already been archived in the O2A archive and more will follow. As part of our campaign, we also recorded video material to create a tutorial for setting up the transect and measuring snow depth. The video was taken by the professional photographer Esther Horvath, who also accompanied the first leg of the MOSAiC expedition. This video will add to our existing video tutorials for the measurements in the snow-free season, which were recorded in Iškoras (Northern Norway) September last year by Hanna Lee's (NTNU, Norway) research group (*https://youtu.be/pFVKnXULnA0*).

We approached some of the INTERACT sites again about our T-MOSAiC permafrost thaw protocol. Happily, several INTERACT stations have joined our project and will start measure-ments this year. These stations include: Greenland (Zackenberg, Disko), Svalbard (CZ Observatory at CNR Arctic Station "Dirigibile Italia"), Siberia (Samoylov), Alaska (Toolik Lake), Fin-land (Kevo) and Canada (Canadian High Arctic Research Station (CHARS) campus and Churchill Northern Studies Center (CNCS).

Our permafrost thaw protocol is now available in form of an app which allows you to enter and upload your measurements, enabling standardized data collection and transfer. This **myThaw** app can be downloaded here: https://www.thea-app.de/download/mythaw_1_2_0.apk (currently for android smartphones only). We plan to distribute our protocol and app widely along with our paper currently in review in the special T-MOSAiC issue of the journal "Arctic Science". If you would like to use the app for your field work this year, please contact us for further information:
https://www.t-mosaic.com/permafrost-thaw.html

## Remote Sensing AG

It has been a difficult early 2021 for many members of the remote sensing action group. The pandemic has affected field work for many of us, while it will still affect next summer's activities, especially for those living in non-Arctic regions. The situation during the last year has also shown how relevant satellite remote sensing becomes, since it provides observational data even when field activities are suspended. The main problem is, however, field validation and ground truth data collection, as well as the maintenance of in situ observatories, so important for the accurate use of remote sensing products. And this is a large problem for many of us in the T-MOSAiC remote sensing action group, with the full summer seasons of 2020 and in many areas, also that of 2021, entirely lost. As such, many of us have focused in data analysis, manuscript writing and, of course, presenting results in international conferences. Fortunately, some projects have been extended, which allow the continuation of the research, but unforeseen field data gaps now affect our knowledge of the Arctic, and it is something that cannot be recovered at all.

In the first months of 2021, the remote sensing action group has organized a vPICO session at the European Geosciences Union General Assembly in the 28th April on "Facilitating remote sensing applications across the terrestrial Arctic" lead by Annett Bartsch, Jeffrey Kirby and Gonçalo Vieira. The session showcased some of the ongoing action group activities in Alaska, Western Canadian Arctic, Northern Quebec and Siberia. The presentations are available online for those that have registered in the conference. Several Action Group members have been involved in the coordination of the session on the "Arctic in transition: monitoring ecosystem change from the ground, air and space", held at the Arctic Science Summit Week 2021 in the 24th March.

EO4PAC (Earth Observation for Permafrost – dominated Arctic Coasts) is a new project linking the T-MOSAIC action groups on remote sensing, permafrost, transects, coasts and infrastructure. The project is funded through the ESA Polar Science Cluster - Collaborative Research and Networking Actions Program and will kick-off in July 2021 running for two years. It aims at the development of a roadmap for the next generation of the Arctic Coastal Dynamics database. The focus is on complementation of in situ records with satellite data across the entire Arctic. The project sub-tasks are lead by Hugues Lantuit, Gonçalo Vieira, Julia Boike and Guide Grosse and the overall action is coordinated by Annett Bartsch.

## Arctic Infrastructure AG

Our Arctic Infrastructure Science Talk series is on hiatus for the summer field season. Our next talk will be on September 16 at 17:00 GMT with Annett Bartsch of b.geos & Austrian Polar Research Institute, Vienna, Austria, on circumpolar infrastructure mapping and classification using remote sensing.

Anyone interested in the participating in the science talk series can find information on past and upcoming presentations _here_. They can also join the Action Group mailing list _here_.

## Special Section: Transects Across the Many Arctics
### Edited by Warwick F. Vincent, co-chair of T-MOSAiC and the Arctic Transects Action Group

If there is one thing we can be sure of as northern researchers, it is that the Arctic is not a single place. Of course, there are commonalities – the feisty northern climate of extreme cold and blizzards, the pervasive influence of snow, ice and frozen ground, and the dramatic seasonality. Yet there are striking differences across the Arctic region in geosystems and ecosystems, and in the Indigenous cultures and languages that have evolved on these lands over millennia.

These contrasts are especially apparent if we travel northwards, from taiga to the Arctic coastline. Northern transects provide compelling natural experiments to learn more about the structure and functioning of the vast terrestrial Arctic, and its linkages to the sea-ice covered ocean over the past, present and future. In this issue of the T-MOSAiC Bulletin, we highlight and connect a number of these transect studies, which illustrate many of our system-level themes in T-MOSAiC such as gradients, connectivity, thresholds, and vulnerabilities to climate change.

The section begins with short graphical abstracts that describe a set of past, ongoing or new transect projects: the Siberian Megatransect; Canada's northern gradients; circumpolar Arctic vegetation transects led by the USA and Russia; the newly established Germany-Russia paleo-transect in Siberia (the Yakutia-Chukotka Transect); the new Greenland GIOS Transect; the PACEMAP paleo-transect in eastern Canada; and the panarctic remote sensing transect to analyze permafrost disturbance. Longer contributions about three of these transect studies are appended in the final pages of this issue, on Siberia, Greenland and snow gradients in eastern Canada.

João Canário and I thank all of the authors for their contributions, and we look forward to hearing from you about other northern transect research, at all scales, that is planned or underway.

# THE SIBERIAN MEGA-TRANSECT
## Natural Largescale Infrastructure for Arctic Transdisciplinary Research

Sergey Kirpotin

Bio-Clim-Land Center of Excellence, Tomsk State University, Russia

In this project we have developed the concept of Western Siberia as a vast natural mega-facility and research platform for network projects and research consortia. The Siberian Environmental Change Network (SECNet) was established in 2016 with the aim to conduct surveys, monitoring, sampling, and experimental work over the 'Siberian Mega-Transect', extending 2500 km from the Altai Mountains in Southern Siberia at the border with Mongolia to the deep Arctic in the Yamal peninsula (Kirpotin et al. 2018). In the future, the aim is to establish an even more extensive transect from the West to the East (about 5000 km) along the gradient of continentality from the Ob river basin to the Kolyma river basin in Yakutia as a new dimension to the Trans-Siberian Scientific Way project. Through T-MOSAiC, the Siberian Mega-Transect has been connected to the Canadian project 'Gradient nordique', with joint activities also connected to INTERACT, NEON, and NASEC. (Kirpotin et al. 2021; see also the article in this bulletin, below).
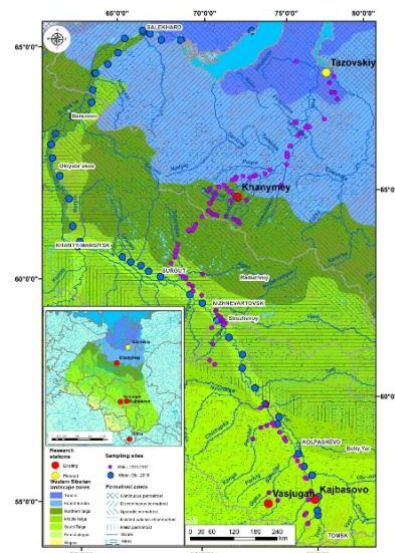
Kirpotin, S., T.V. Callaghan, O. Pokrovsky, J. Karlsson, S.N. Vorobiov, L.G. Kolesnichenko, I.G. Popravko, T.S. Kolesnikova, et al. 2018. Russian–EU collaboration via the mega-transect approach for large-scale projects: Cases of RF Federal Target Programme and SIWA JPI Climate EU Programme. *International Journal of Environmental Studies* 75: 385–394. doi: 10.1080/00207233.2018.1429131.

Kirpotin S., Callaghan T.V., Peregon A.M., Babenko A.S., Berman D. I., Bulakhova N.A., Byzaakay A.A., et al. 2021. Impacts of climate change on vegetation dynamics and biodiversity in Siberia. Special Issue on Siberian Environmental Change. *Ambio*.  doi: 10.1007/s13280-021-01570-6.

# GRADIENT NORDIQUE - CANADA'S NORTHERN GRADIENTS
## Critical Thresholds across a 3000 km Transect

Émilie Saulnier-Talbot[1,2,3], Warwick F. Vincent[1,3] and Joël Bêty[1,4]
[1]Centre d'études nordiques, [2]Québec-Océan, [3]Université Laval & [4]Université du Québec à Rimouski, Canada

Centre d'études nordiques (CEN: Centre for northern studies) is celebrating its 60th anniversary in 2021 and many of our researchers and collaborators are bringing together their current and past observations on northern ecosystems and geosystems from their work in eastern Canada. The project connects CEN field stations and study sites, and extends across ecozones in a North-South transect from the extreme High Arctic polar desert (Ward Hunt Island, 83.1°N) to the boreal forest of eastern James Bay (53.7°N). By considering vegetation, permafrost, wetlands, lakes, snow and vertebrate assemblages, we are determining latitudes where state shifts could occur under a warmer climate (see Saulnier-Talbot et al. 2020). An analysis of snow data along the transect has also been published (Royer et al. 2021; see also the article in this bulletin, below).

Royer, A., Domine, F., Roy, A., Langlois, A., Marchand, N. and Davesne, G., 2021. New northern snowpack classification linked to vegetation cover on a latitudinal mega-transect across northeastern Canada. *Écoscience*, doi: 10.1080/11956860.2021.1898775.

Saulnier-Talbot, É., Antoniades, D. and Pienitz, R., 2020. Hotspots of biotic compositional change in lakes along vast latitudinal transects in northern Canada. *Global Change Biology* 26: 2270-2279. doi: 10.1111/gcb.15016.

# CIRCUMPOLAR ARCTIC VEGETATION TRANSECTS
## Climate Drivers of Variability and Change

D.A. Skip Walker[1], Howie E. Epstein[2], Uma Bhatt[1], Martha Raynolds[1], Vlad Romanovsky[1], and Marina Liebman[3]

[1]University of Alaska Fairbanks, USA; [2]University of Virginia, USA; [3]Earth Cryosphere Institute, RAS, Moscow, Russia

Our combined group at University of Alaska, University of Virginia, and a large group of international collaborators, including the Earth Cryosphere Institute in Moscow, have a long-term interest in Arctic Transects. This interest dates to a 1999 transect established to examine differences in Canadian vegetation in relation to the north-south bioclimate subzones and floristic differences associated with East-West floristic provinces of the Circumpolar Arctic Vegetation Map. We have established four north-south transects in the Arctic: (1) Eastern Canada Arctic Transect (1999) Daring Lake, NWT; Cambridge Bay, Victoria I.; Resolute, Cornwallis I.; Eureka, Ellesmere I.; Stratigrapher Creek, Amund Ringnes I.; northern Axel Heiberg I. (2) North America Arctic Transect (NAAT) (2001-2006) Happy Valley, Sagwon, Franklin Bluffs, West Dock, Howe Island, AK; Green Cabin, Banks I.; Mould Bay, Prince Patrick I.; Isaacsen, Ellef Ringnes I. (3) Kolyma River Arctic Transect (2002) Cherski, Kurishka, Sukarnoye, Ambarchik, Mys Medveshy. (4) Eurasia Arctic Transect (EAT) (2007–2011) Yamal Peninsula: Nadym, Laborovaya, Vaskiny Dachi, Kharasavey, Ostrov Belyy; Hayes I., Franz Josef Land. The two most thoroughly studied transects are the NAAT and EAT where detailed vegetation and biomass information have been studied in relationship to summer land temperatures, permafrost temperatures, active layer depths, sea-ice extent, and satellite-derived indices of vegetation greenness (figure above, from Raynolds et al. 2012; see also Epstein et al. 2021). Current work includes development of climate and vegetation indices as indicators of Arctic change (Bhatt et al. 2021).
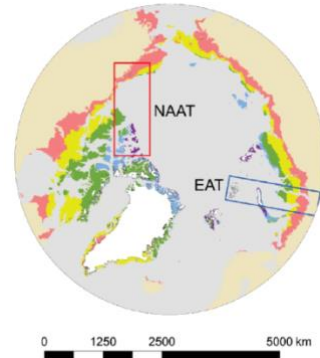
Bhatt, U. S., D. A. Walker, M. K. Raynolds, J. E. Walsh, P. A. Bieniek, L. Cai, J. C. Comiso, H. E. Epstein, et al. 2021. Climate drivers of arctic tundra variability and change using an indicators framework. *Environmental Research Letters* 16:055019. doi: 10.1088/1748-9326/abe676.

Epstein, H. E., D. A. Walker, G. V. Frost, M. K. Raynolds, U. Bhatt, B. C. Forbes, J. Geml, E. Kaarlejävi, et al. 2021. Spatial patterns of arctic tundra vegetation biomass, NDVI, and LAI on different soils along the Eurasia Arctic Transect, and insights for a changing Arctic. *Environmental Research Letters* 16:014008. doi: 10.1088/1748-9326/abc9e3.

Raynolds, M.K., Walker, D.A., Epstein, H.E., Pinzon, J.E. and Tucker, C.J. 2012. A new estimate of tundra-biome phytomass from trans-Arctic field data and AVHRR NDVI. *Remote Sensing Letters* 3:403-411. doi: 10.1080/01431161.2011.609188.

# NEW YAKUTIA-CHUKOTKA TRANSECT OF ENVIRONMENTAL STUDIES, SIBERIA
## Ecological and Environmental Transitions

Ulrike Herzschuh[1] and Luidmila A. Pestryakova[2]

[1]Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany; [2]Northeastern Federal University, Yakutsk, Russia

Researchers from the Alfred Wegener Institute in Potsdam and Northeastern Federal University in Yakutsk established the Yakutia-Chukotka Transect to study present and past environmental change. This builds on our almost 20-year-long Russian-German collaboration in environmental research in northeastern Siberia; e.g., Herzschuh et al., (2013); Pestryakova et al., (2016), Shevtsova et al. (2020). The transect covers the transition from evergreen boreal forests to deciduous boreal forests on permafrost in the southwestern part and the forest-tundra transition in the northeastern part. We investigate biodiversity, vegetation, soil and lake parameters in the course of climate, fire and land-use changes using a variety of methods. Furthermore, we analyze lake sediments to reconstruct past ecological and environmental transitions applying, for example, sedimentary ancient DNA analyses (Stoof-Leichsenring et al. 2021). Photograph: Investigations of larch individuals (*Larix*) in the treeline region of Chukotka (photocredit: S. Kruse, AWI).

Stoof-Leichsenring, K.R., Liu, S.S., Jia, W.H., Li, K., Pestryakova, L.A., Mischke, S., Cao, X.Y., Liu, X.Q., Ni, J., Neuhaus, S., Herzschuh, U., 2021. Plant diversity in sedimentary DNA obtained from high-latitude (Siberia) and high-elevation lakes (China). *Biodiversity Data Journal* e57089, 10.3897/BDJ.8.e57089.

Shevtsova, I., Heim, B., Kruse, S., Schröder, J., Troeva, E., Pestryakova, L., Zakharov, E., Herzschuh, U., 2020. Strong shrub expansion in tundra-taiga, tree infilling in taiga and stable tundra in central Chukotka (north-eastern Siberia) between 2000 and 2017. *Environmental Research Letters* https://doi.org/10.1088/1748-9326/ab9059.

Herzschuh, U., Pestryakova, L.A., Savelieva, L.A., Heinecke, L., Böhmer, T., Biskaborn, B.K., Andreev, A., Ramisch, A., Shinneman, A., L.C., Birks, H.J.B., 2013. Siberian larch forests and the ion content of thaw-lakes form a geochemically functional entity. Nature Communications 4, 2408. https://doi.org/10.1038/ncomms3408.

Pestryakova, L.A., Herzschuh, U., Gorodnichev, R., Wetterich, S., 2016. The sensitivity of diatom taxa from Yakutian lakes (north-eastern Siberia) to electrical conductivity and other environmental variables. Polar Research 37, No. 1485625. https://doi.org/10.1080/17518369.2018.1485625.

# GIOS
## Greenland Integrated Observing System

Torben Røjle Christensen and Søren Rysgaard
Arctic Research Centre, Aarhus University, Denmark

GIOS is a new, comprehensive and coordinated partnership to research and monitor climate change in the Arctic environment. GIOS builds on long time-series of data from several existing programs such as the Greenland Ecosystem Monitoring program (GEM), complementing these with a transect approach to multiple studies and infrastructure supporting it along the East Coast of Greenland. The joint effort covers the collection of data on the Greenland ice sheet, seasonal snow and sea ice, the evolution of permafrost, landscapes and ecosystems, hydrologic and oceanographic conditions in and surrounding Greenland, and atmospheric composition, meteorology and geomagnetic conditions. The ensemble of GIOS data will provide the necessary ground truth for satellite measurements, for development and testing of models for understanding the mechanisms behind the ongoing changes across the Greenland and its neighboring regions (e.g., Christensen et al. 2021). Further details are provided below in this bulletin, and updated information is available on the GIOS website: www.gios.org.
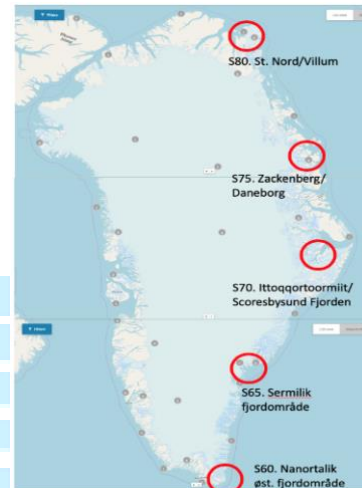
Christensen, T.R., Lund, M., Skov, K., Abermann, J., Lopez-Blanco, E., Scheller, J., Scheel, M., Jackowicz-Korczynski, M., Langley, K., Murphy, M.J. and Mastepanov, M. 2021. Multiple ecosystem effects of extreme weather events in the Arctic. *Ecosystems*, 24: 122-136. https://link.springer.com/content/pdf/10.1007/s10021-020-00507-6.pdf.
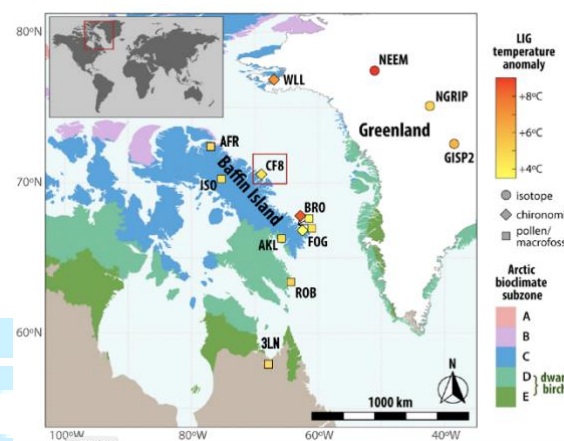
# PACEMAP
## Predicting Arctic Change through Ecosystem Molecular Proxies

Gifford Miller

Institute of Arctic and Alpine Research and Department of Geological Sciences,
University of Colorado Boulder, USA

PACEMAP is an interdisciplinary project involving scientists from the University of Colorado Boulder, the University at Buffalo, University of Alaska Fairbanks, the University of Münster, Germany, and Curtin University in Australia. It brings together ecologists, geologists, paleoclimatologists, organic geochemists and geneticists, with the aim to use the past to predict the future. Capitalizing on lake sediment deposited in past warm times on Baffin Island, including the Early Holocene, the Last Interglacial, and the penultimate interglacial, field teams are recovering pristine continuous sedimentary records that span earlier warm intervals. The team is using molecular approaches to reconstruct changes in climate, hydrology, and vegetation through past warm times. Ancient sedimentary DNA extracted from interglacial sediment provides a more authentic reconstruction of local vegetation communities, where long-distance pollen dispersal complicates pollen records. This approach, relatively untested on such long timescales, also involves modern validation work, where collaborators at University of Alaska Fairbanks and University of Münster, map the modern vegetation around the study sites to compare with DNA extracted from surface sediments at our coring sites along a South-North Transect. This extends across eastern Canada, from treeline in northern Québec (3LN, near Kuujjuaq, Nunavik), through Baffin Island (Nunavut), with the cold end-member a lake almost 1000 m asl at the northern tip of Baffin Island (AFR; see figure, modified from Crump et al. 2021).

Crump, S.E., Fréchette, B., Power, M., Cutler, S., de Wet, G., Raynolds, M.K., Raberg, J.H., Briner, J.P., Thomas, E.K., Sepúlveda, J., Shapiro, B., Bunce, M., and Miller, G.H. 2021. Ancient plant DNA reveals High Arctic greening during the Last Interglacial. *Proceedings of the National Academy of Sciences*, *118*; e2019069118. doi: 10.1073/pnas.2019069118.

## PANARCTIC REMOTE SENSING TRANSECTS
### Disturbances across permafrost landscapes

Guido Grosse[1,2] and Ingmar Nitze[1]

[1]Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany; [2]University of Potsdam, Institute of Geosciences, Germany

Four continental-scale transects (T1: Western Siberia; T2: Eastern Siberia; T3: Alaska; and T4: Eastern Canada) covering a total of about 2.3Mkm[2] (~10% of the northern permafrost region) were defined for remote sensing studies of permafrost region disturbances (see figure, from Nitze et al., 2018a) within the ESA GlobPermafrost project (Bartsch et al. 2016). The transect regions were chosen to produce maximum overlap with other existing studies of ecosystem, permafrost, and climate gradients. The focus of the remote sensing work was on using the comprehensive Landsat satellite archive (TM, ETM+, OLI) for the 1999-2014 period with its multispectral imagery at 30m resolution to produce a spatially continuous and consistent data product of disturbance trends for the full extent of the transect.
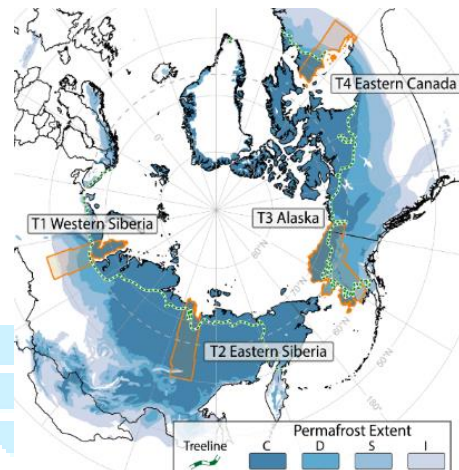
The primary product includes the Hot Spot Regions of Permafrost Change (HRPC) datasets of change in land surface characteristics based on trends in the multi-spectral indices Tasseled Cap brightness, greenness, wetness, and normalized indices (Normalized Difference Vegetation Index - NDVI; Normalized Difference Water Index - NDWI; Normalized Difference Moisture Index -NDMI) (Datasets: Nitze 2018; Product Documentation: Nitze et al., 2018b). Land surface changes detectable with the datasets include gradual press disturbances in land cover such as shrub expansion, wetting, drying, and active layer deepening, but also rapid pulse disturbances such as thermokarst and thermo-erosion, lake formation, expansion, and shrinkage, river migration, lake shore and coastal erosion, and wildfires. Secondary products derived from the primary datasets include three specific key permafrost region disturbances (PRD): lakes and their dynamics, wildfires, and retrogressive thaw slumps (Nitze et al., 2018c). The Lake datasets contain the perimeters of maximum extent of individual lakes larger than 1 ha buffered by 30 meters. The Fire datasets contain the perimeters of detected burn scars. The RTS datasets contain the perimeters of detected active retrogressive thaw slumps. The data publication contains geospatial vector files (polygons) of the perimeters of the PRD. Findings and interpretations of changes in the PRD were summarized in Nitze et al. (2018a).

The primary and secondary products are archived and freely available through the open access PANGAEA World Data Centre (www.pangaea.de) archive and accessible through the Arctic Permafrost Geospatial Centre (APGC, https://apgc.awi.de). From the APGC, the data products can be easily searched, metadata reviewed, and datasets can be directly pulled into the open access desktop GIS software QGIS.

Bartsch, A., Grosse, G., Kääb, A.. Westermann, S., Strozzi, T., Wiesmann, A., Duguay, C., Seifert, F.M., Obu, J., Goler, R. 2016. GlobPermafrost – How space-based earth observation supports understanding of permafrost. *Proceedings of the ESA Living Planet Symposium*, pp. 6.

Nitze, I. 2018. Trends of land surface change from Landsat time-series 1999-2014. *PANGAEA*, https://doi.org/10.1594/PANGAEA.884137

Nitze, I., Grosse, G., Jones, B.M., Romanovsky, V.E., Boike, J. 2018a. Remote sensing quantifies widespread abundance of permafrost region disturbances across the Arctic and Subarctic. *Nature Communications,* 9, 5423. https://doi.org/10.1038/s41467-018-07663-3.

Nitze, I., Grosse, G., Heim, B. 2018b. Product documentation: Hot Spot Regions of Permafrost Change ("Hot Spot Product"). Bremerhaven, *PANGAEA*. hdl:10013/epic.bd059e90-648e-4a0b-af06-609579e4fc20.

Nitze, I., Grosse, G., Jones, B.M., Romanovsky, V.E., Boike, J. 2018c. Remote sensing quantifies widespread abundance of permafrost region disturbances across the Arctic and Subarctic, Datasets. *PANGAEA*, https://doi.org/10.1594/PANGAEA.894755,

**ARCTIC TRANSECTS - ARTICLES**

**Kirpotin, S.N. ………………....** Siberia as 'natural collider': the Siberian mega-transect

**Christensen, T. ………………..** Greenland integrated observing system (GIOS)

**Royer, A., et al. ……………….** Two decades of snow studies over a 4000 km transect, from 47°N to 83°N in Eastern Canada

# SIBERIA AS 'NATURAL COLLIDER': THE SIBERIAN MEGA-TRANSECT

Sergey N. Kirpotin

Bio-Clim-Land Center of Excellence, Tomsk State University, Russia

In establishing our northern research network SECNet, a unique concept was developed as a methodological basis for our collaborative science activities across disciplines: the concept of Western Siberia as a unique natural mega-facility and the mega-transect approach as its infrastructural axis for research. The term 'mega-science' usually concerns physics. Largescale scientific infrastructure like CERN's Large Hadron Collider is so expensive that no one country in the World, even the richest ones, can pay for its installation and operations. Therefore, different countries and leading scientific centres pool their resources for the development of mega-science, and scientific consortia are formed to work at these mega-facilities. For any research organization, it is incredibly encouraging and productive to become a member of such a consortium.

As a result of long-term multidisciplinary research in Siberia and taking into account the global significance of this region, Tomsk State University, located at the Eurasian midpoint, developed the concept of Western Siberia as a unique natural mega-facility possessing exceptional global significance, attractive to the world scientific community and capable of becoming a research platform for organizing large network projects and research consortia. Accordingly, the Siberian Environmental Change Network (SECNet) was established in 2016, focused on Western Siberia as a kind of 'natural collider' equivalent to CERN, to attract leading international research groups (Kirpotin et al., 2018). The mega-transect across this region can be studied in all seasons, for field sampling and ground-based research at the field stations in combination with ecosystem manipulations, experiments and remote sensing.
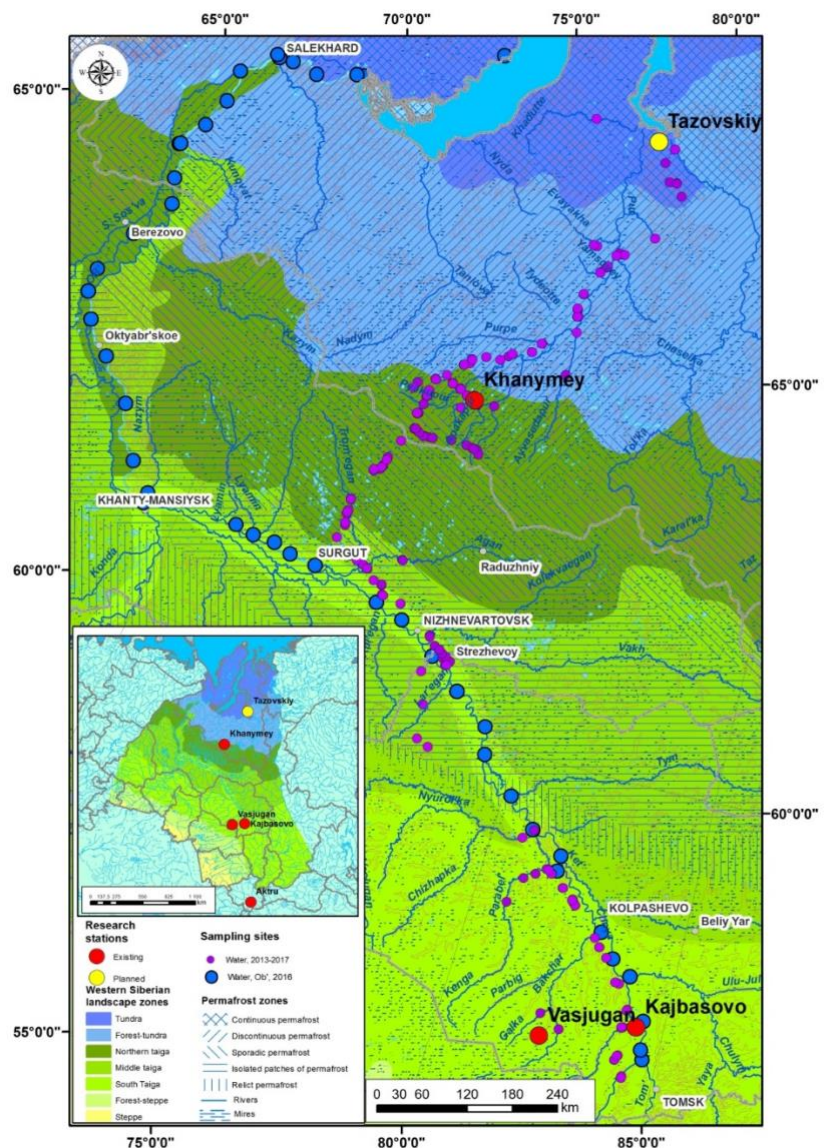


The Western Siberian Mega-Transect extends 2500 km from the Altai Mountains in Southern Siberia at the border with Mongolia to the deep Arctic in the Yamal peninsula (see figure). A cluster of research stations has been set up along the mega-transect: Aktru (North-Chuya Ridge, South-Eastern Russian Altay), Kaibasovo (the mid-course floodplain of the Ob River), and Khanymey (the southern edge of the permafrost zone). Some of the

research stations were included in the circumpolar network of research stations INTERACT-II, the largest project of the EU's program Horizon 2020. In the future, it is proposed to establish an even more extended trans-meridional mega-transect from the West to the East (about 5000 km) along the gradient of continentality from the Ob river basin to the Kolyma river basin in Yakutia, additionally including the basins of the biggest river estuaries in the Arctic Ocean: Yenisei, Lena and Indigirka. This mega-transect will contribute a new dimension to the Trans-Siberian Scientific Way project (Kirpotin et al., 2018).

The infrastructure of the West Siberian mega-facility and research mega-transect gives unprecedented opportunities, providing logistics for high-level field research at the framework of large-scale national and international projects (Kirpotin et al., 2018). In December 2017, the Mega-Transect Project and successful experience of the TSU Bio-Clim-Land Center in organizing large-scale scientific research based on a mega-transect approach was presented by Sergey Kirpotin for the Steering Committee of the new pan-Arctic programme T-MOSAiC (Terrestrial - Multidisciplinary distributed Observatories for the Study of Arctic Connections), formed by the International Arctic Scientific Committee (IASC) at its 2017 meeting in Prague, Czech Republic. Russia's achievement in organizing and successfully operating the world's first mega-transect for research and all-season environmental monitoring was recognized and approved by the Executive Committee of T-MOSAiC as one of the key drivers for its development.



*Sergey Kirpotin (Chair of the Arctic Transects Action Group of T-MOSAiC), Mélanie Lemire (Professor and Chair in Northern Health, Université Laval) and Warwick Vincent (co-Chair of T-MOSAiC) at the Arctic Change conference in 2017.*

An analogous transect for research, called 'Gradient nordique' (Canadian Northern Gradients) had been launched in Canada by the Centre for Northern Studies (CEN), and was presented along with the Siberian latitudinal Mega-Transect at the T-MOSAiC inaugural workshop held during the Arctic Change conference in Quebec City in 2017. The Russian and Canadian delegations at that meeting proposed the docking of these two mega-structures. There was great interest and agreement to conduct parallel studies on terrestrial geosystems and ecosystems based upon common concepts and protocols (http://www.tsu.ru/news/uchenyy-tgu-voshel-v-novyy-mezhdunarodnyy-arktiche/ )

In the future, it is proposed to create an even more extended transmeridional mega-transect from the west to the east (about 5000 km) along the gradient of continentality from the Ob basin to the Kolyma River basin in Yakutia, including additionally the basins of the mouths of the largest rivers of the Arctic Ocean: Yenisei, Lena and Indigirka. This mega-profile will add a new dimension to the Trans-Siberian Scientific Route project (Kirpotin et al., 2018). The idea of creating a transmeridional mega-profile was enthusiastically supported by leading scientific groups in France and Germany.

Since its founding, the SECNet has been focused on large-scale interaction with society, regional authorities and indigenous people on the basis of a trans-disciplinary approach. It actively cooperates in this context with networks in addition to T-MOSAiC, including INTERACT, NEON and NASEC (Kolesnikova et al., 2020).

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**GREENLAND INTEGRATED OBSERVING SYSTEM (GIOS)**

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**GIOS** is a new, comprehensive and coordinated, joint effort from the Danish realm, to provide new knowledge about the climate change in the Arctic environment, how quickly the changes occur and how they can affect the rest of the globe. **GIOS** boosts collaboration between all Arctic research environments within the Danish realm to ensure it maintain a leading role in Greenland environmental research and a well-informed Arctic voice in the international debate. **GIOS** develops sustainable research infrastructure in and around Greenland. Where possible, GIOS stations will be supplied with green energy and will continuously monitor condition of the air, ice, sea and land. **GIOS** covers the entire climate gradient in the Arctic and ensures an easy, open and fast access to measured data for everyone worldwide.

**ONE ACCESS POINT TO ALL GIOS DATA**

GIOS makes its open data available globally and thus links Greenland research across scientific disciplines and various other stakeholders. In combination with improved and interlinked logistics, GIOS is designed to attract international partners and promote research of the highest of international standards. The GIOS data resource ensures the necessary ground truth data for satellite measurements and offers far better options to test and develop more robust models that remain an essential tool for understanding the mechanisms behind the ongoing changes across the Greenland and its neighboring regions

**JOINT RESEARCH IN THE ARCTIC**

The GIOS partnership is comprehensive across Arctic research; developing and streamlining data collection in and around Greenland. GIOS partner institutions include: the Greenland Institute of Natural Resources; Aarhus University; Copenhagen University; Technical University of Denmark; The Geological Survey of Denmark and Greenland, Asiaq the Greenland Survey, Aalborg University. Affiliated partners include: Danish Meteorological Institute; Danish Arctic Command;University of Southern Denmark; Greenland National Museum;University of Greenland and Havstoven in the Faroe Islands.

The joint effort covers the collection of data on:
* the Greenland ice sheet, seasonal snow and sea ice;
* the evolution of permafrost and terrestrial and marine ecosystems hydrologic and oceanographic conditions in and surrounding Greenland
* atmospheric composition, meteorology and geomagnetic conditions.


NEW DATA FROM SUSTAINABLE MEASUREMENT STATIONS
The GIOS partnership develops and implements:
* instrumentation that measures conditions on land, in the atmosphere, in fresh water and the ocean. The measuring stations form nodes from which data is continuously recorded and transmitted. The measurements are kept running by solar and wind energy, reducing the environmental footprint of the data collection and ensuring the data collection can take place year round.

- profiling buoys measure physical, chemical and biological conditions in the ocean.
- airborne sensors measure snow depth and sea ice thickness.
- atmospheric and ecosystem stations measuring greenhouse gas fluxes,concentrations and space weather.
- climate chambers inform biological studies of climate effects.
- a mobile ice camp supports observation of the ice sheet.

The expansion of the research infrastructure maintains and expands the long-term climate records that have been collected across Greenland. The data records allow for documenting the fast changes in the Arctic. The new GIOS infrastructure provides data that complements the data records that are vital to understand and explain the mechanisms behind the observed changes.

### GREENLAND GRADIENT AS PART OF GIOS

GIOS includes a transect approach to multiple studies and infrastructure supporting it along the East Coast of Greenland. This is building directly from first investments made in the concept through donations from the Aage V. Jensen Foundations in 2020 and 2021.
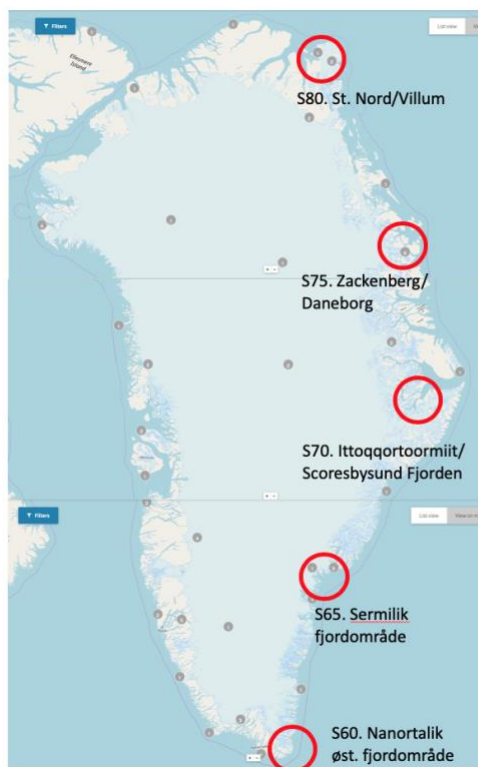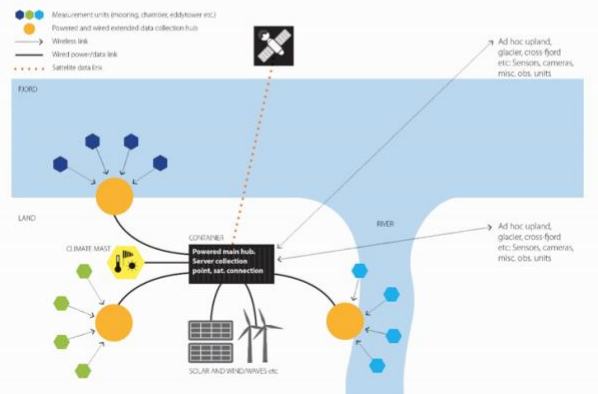




www.gios.org

Now funded (2021-2026) by the Danish Ministry for Higher Education and Research, GIOS was in an early White Paper version presented to the Arctic Observing Summit in 2020:
https://arcticobservingsummit.org/sites/default/files/2019_007_GIOS%20White%20Paper%20AOS_191119.pdf

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# TWO DECADES OF SNOW STUDIES OVER A 4000 KM TRANSECT, FROM 47°N TO 83°N IN EASTERN CANADA

### *A contribution to IASC T-MOSAiC 'Arctic Transects' and CEN 'Gradient nordique'*

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It may be difficult believe that the COVID-19 crisis could have some positive outcomes, yet here is an example. At the beginning of the first lockdown in February 2020, as our "winter laboratory", the North, was closed to visitors and we were all stuck at home, I set out to gather all the snow data we had collected over the past 20 years, along with my snow science colleagues Florent Dominé of Université Laval, Alex Langlois of Université de Sherbrooke and Alex Roy of the Université du Québec à Trois-Rivières. It was a year of "deep searching" in our archives, a rather tedious but ultimately very conclusive research. These 20 years of measurements of the physical properties of snowpack have allowed us to gather a unique database, the results of 25 field campaigns at nearly 45 different sites spread out along a 4,000 km south-north transect over northeastern Canada, from the Mauricie region (47°N) to the extreme north of Canada, at Ward Hunt Island (83°N). This represents approximately 200 tons of snow digging!

Changes in mass, extent, duration, and physical properties of snow are key elements for studying associated climate change feedbacks in northern regions. However, current snow models fail to represent the main physical characteristics of the Arctic snowpack. This leads to large uncertainties in the modelling of future snow feedbacks on the ground thermal regime caused by the changes in snow insulation they induce. This study aimed to characterize main regional physical properties of boreal, subarctic and Arctic snow in order to help test and validate snow physics models and continental surface models. For each sampled site, the dataset includes snow depth (SD, cm), snow water equivalent (SWE, kg m$^{-2}$), bulk density (kg m$^{-3}$), depth hoar layer thickness (when present) (cm) and depth hoar fraction (unitless, ratio of the depth hoar layer thickness over the snow depth).

Two very interesting results emerge from this study, which has recently been published in the journal *Écoscience*[1], a special issue produced for the 60th anniversary of our Centre for Northern Studies (Centre d'études nordiques, CEN). The study is also a contribution to the CEN project 'Gradient nordique' (see the abstract by Saulnier-Talbot et al., in this edition of the T-MOSAiC Bulletin). The results of our data compilation and analysis provide explicit evidence that snow, thought to be defined solely by climate, is in fact also strongly linked to the vegetation cover. Figure 1 shows all the SD, SWE and density values analyzed in terms of their mean and variability (standard deviation) as a function of latitude over the studied transect. The data grouped show three statistically distinct classes of snowpack, leading us, using also additional microstructure snowpack and land-cover analysis, to propose a new updated snow classification: (1) boreal forest snow (47–58°N); (2) tundra snow (58–74°N); (3) polar desert snow (74–83°N). Such a new classification is unlike the one used for the last 25 years by the cryosphere science community.

Observed changes in snowpack properties along the transect driven by climate conditions arise also from the strong land surface processes generated by the vegetation cover. In particular, the shrubs that are invading the North as a result of global warming are modifying the microstructure of the basal layers of the snowpack by promoting the development of "depth hoar", with snow grains that are sometimes more than 1 to 3 cm in size. Figure 2 illustrates what may be considered representative density profiles for each snow class. Typically, density increases towards the bottom of the sub-Arctic snowpack while it is reversed for the Arctic and polar desert snow with high density at the surface (wind slab) and low density at the bottom with depth hoar. These low-density basal layers contribute to significantly increase the thermal insulation properties of the snowpack and thus to warm the ground. In the context of the "greening of the North", which is well characterized by satellite (Figure 3), this analysis suggests that these snow-vegetation interactions may enhance snow feedbacks on northern warming, including accelerating permafrost thaw in the Arctic.

This novel database has already been used in two ways: 1) to improve and validate the Snow Microwave Radiative Transfer Model (SMRT[2]) used to model microwave satellite measurements, that allows to spatially extend the analysis; and 2) to validate a new Arctic version of the French numerical snow simulation model Crocus[3], that allows temporal extensions of the analysis. This modified version of Crocus showed that the increasing trend in winter soil surface temperature (under the snow) in Arctic over the last 40 years is significantly higher than for the unmodified version. These changes have also resulted in a significant increase in active layer thickness over the same period. Our findings indicate that the observed changes in Arctic snow properties linked to vegetation will likely alter the prediction of snow impact on permafrost evolution, Arctic erosion and hydrology. The full data set is available in the northern environmental data archive *Nordicana*[4].
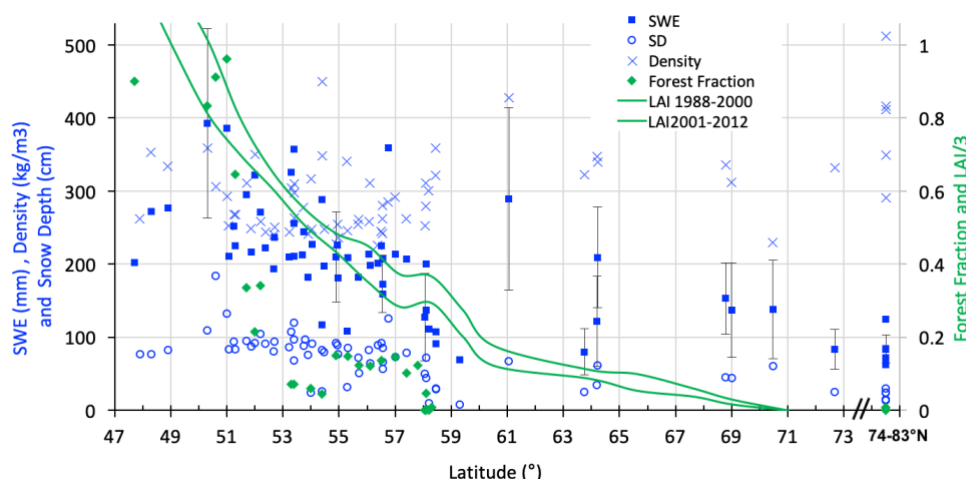
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### Acknowledgments

**Figures**



**Figure 1**: Observational evidence of latitudinal changes in snow water equivalent ($SWE_{max}$, blue squares), snow depth (SD, blue open circles) and density (blue crosses), matched with vegetation properties: continuous satellite-derived leaf area index (LAI, green lines), and forest fraction (crown-closure, summer 2011 images, %, green diamond), over the northeastern Canadian transect studied from 47°N to 83°N. The thick green line is for averaged 1988–2000 LAI, and the thin green line is for 2001–2012 period (right scale). Vertical bars show the ranges of $SWE_{max}$ local spatial variability (± standard deviation). Note that the latitude axis is stretched between 47° to 73°N for more clarity and that all sites above are set to 74-83°N. These points above 74°N correspond to Resolute (75°N), Eureka (80°N), Alert (82.5°N) and Ward Hunt (83.1°N). Results show that the data can be grouped into three classes: boreal forest snow (47-58°N) with high SD and SWE values but relatively low mean density; tundra snow (58-74°N) with lower SD and SWE but higher density; and polar desert snow (74-83°) with lower SD and SWE but very high density. See Royer et al, (2021)[1]
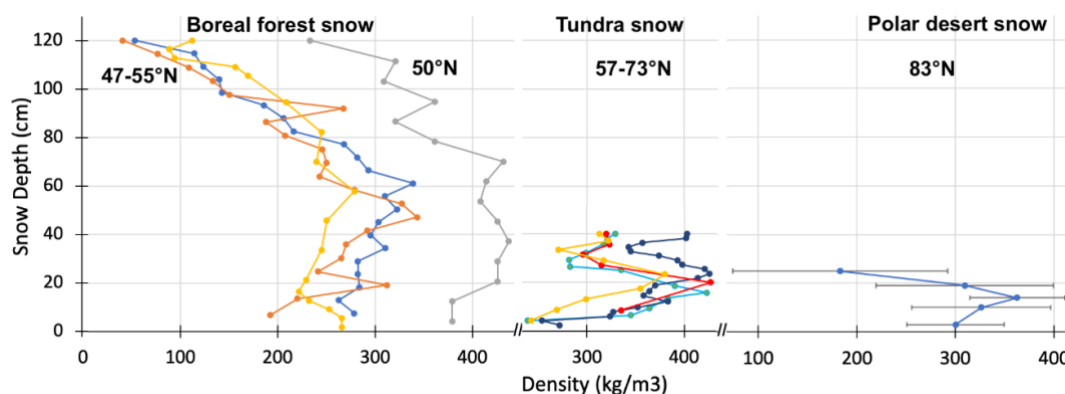


**Figure 2**: Typical examples of density profiles observed for each snow class. Each density profile has been normalized for every class for clarity. Right: Boreal Forest snow profiles (samples from sites at 47°, 50° and 55°N normalized at 120-cm depth); Middle: Tundra snow profiles (samples from sites at 57° and 73°N, normalized at 40-cm depth); Left: Polar desert snow profile (7 profiles averaged from Ward Hunt site, 83°N, with ± 1 standard deviation and normalized at 25-cm depth). The abscissa is discontinuous for each class, with the same scale, to allow more clarity. The density variability can be large, however one can outline typical density behaviors of each of the class, characteristically for the boreal forest snow: a regular decrease in density in the first upper half of the mantle and then an almost constant high density profile until the bottom due to the compaction of the snow; for tundra snow, and more markedly for polar desert snow: we observe a structure in two contrasting layers with a high density rise in the first upper half, and the opposite for the lower layer, towards low densities resulting from the development of depth hoar.

**Figure 3**: Evolution of the Normalized Spectral Vegetation Index (NDVI) on the transect studied in eastern Canada (in percent per decade) derived from satellite images. From one of the longest existing series of satellite images with the AVHRR sensor (NASA Global Inventory Modeling and Mapping Studies dataset from AVHRR: GIMMS3gv1, 1982 to 2016), it is possible to follow the evolution of terrestrial vegetation over 35 years with the NDVI index. Despite strong regional variability over the circumpolar areas, the results of this evolution show a tendency to the spectral "greening" clearly predominant compared to the "spectral browning" derived from this satellite index. There is a 42% increase in vegetation (12.8% in Arctic and 29.1% in boreal area>45°N) compared to a 2.5% (0.8% in Arctic and 1.7% in boreal area) increase in bare soil over the study period [*Park, T. et al. Changes in growing season duration and productivity of northern vegetation inferred from long-term remote sensing data. Environ. Res. Lett. 11, 084001 (2016)*]. Point WH indicates the position of the Ward Hunt Island Observatory at latitude 83.1°N, at the northern tip of Canada, and maintained by CEN in partnership with Parks Canada.