PERMAFROST PATHWAYS

Connecting Science, People, and Policy for Arctic Justice and Global Climate

ARTS: a scalable remote-sensed data set for Arctic Retrogressive Thaw Slumps

Woodwell Climate Research Center

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs
Arctic Initiative

ALASKA INSTITUTE FOR JUSTICE

Retrogressive Thaw Slumps

- Thermal-denudation on ice-rich hillslope permafrost terrain
- Frequent dynamic changes to the landscape
- GHG emission and feedback to the climate
- No existing pan-Arctic map product, lack of representation of abrupt thaw in climate/carbon models

Photo: Scott Zolkos

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DIGITISATION of RTS using satellite images

- Train DL models for RTS detection
- Train ML models to predict RTS susceptibility
- Time-series study of RTS development
- Remote-sensing based mechanism/process study

Existing, Standalone RTS Digitisation Data Sets

Source	RAW RTS count	RAW non-RTS count	Publication
Nitze et al., 2021 Version2	3579	1300	Nitze I, Heidler K, Barth S, et al. Developing and testing a deep learning approach for mapping retrogressive thaw slumps[J]. Remote Sensing, 2021, 13(21): 4294.
Yang et al., 2023	855	3219	Yang Y, Rogers B M, Fiske G, et al. Mapping retrogressive thaw slumps using deep neural networks[J]. Remote Sensing of Environment, 2023, 288: 113495.
Huang et al., 2022	621		Huang, L., Lantz, T. C., Fraser, R. H., Tiampo, K. F., Willis, M. J., & Schaefer, K. (2022). Accuracy, Efficiency, and Transferability of a Deep Learning Model for Mapping Retrogressive Thaw Slumps across the Canadian Arctic. Remote Sensing, 14(12), 2747.
Witharana et al., 2022	356		Witharana C, Udawalpola M R, Liljedahl A K, et al. Automated Detection of Retrogressive Thaw Slumps in the High Arctic Using High-Resolution Satellite Imagery[J]. Remote Sensing, 2022, 14(17): 4132.
Segal et al., 2015	832		R.A. Segal, T.C. Lantz, and S.V. Kokelj, NWT Open Report 2015-021: Inventory of active retrogressive thaw slumps on eastern Banks Island, Northwest Territories, 2015
Huang et al., 2023	2494		Huang L, Willis M J, Li G, et al. Identifying active retrogressive thaw slumps from ArcticDEM[J]. ISPRS Journal of Photogrammetry and Remote Sensing, 2023, 205: 301-316.
Bernhard et al., 2022a	1832		Bernhard P, Zwieback S, Bergner N, et al. Assessing volumetric change distributions and scaling relations of retrogressive thaw slumps across the Arctic[J]. The Cryosphere, 2022, 16(1): 1-15.
van der Sluijs et al., 2022	2661		van der Sluijs J, Kokelj S V, Tunnicliffe J F. Allometric scaling of retrogressive thaw slumps[J]. The Cryosphere Discussions, 2022, 2022: 1-30.
Bernhard et al., 2022b	1487		Bernhard P, Zwieback S, Hajnsek I. Accelerated mobilization of organic carbon from retrogressive thaw slumps on the northern Taymyr Peninsula[J]. The Cryosphere, 2022, 16(7): 2819-2835.
Lin et al., 2023	365		A transfer learning approach for automatic mapping of retrogressive thaw slumps (RTSs) in the western Canadian Arctic
Ramage et al., 2017	286		Ramage, Justine L; Irrgang, Anna Maria; Herzschuh, Ulrike; Morgenstern, Anne; Couture, Nicole; Lantuit, Hugues (2017): Terrain controls on the occurrence of coastal retrogressive thaw slumps along the Yukon Coast, Canada. Journal of Geophysical Research-Earth Surface, 122(9), 1619-1634,
Nicu et al., 2021	562		Nicu I C, Lombardo L, Rubensdotter L. Preliminary assessment of thaw slump hazard to Arctic cultural heritage in Nordenskiöld Land, Svalbard[J]. Landslides, 2021, 18(8): 2935-2947.
Elia et al.,	690		
Leibman et al., 2023	97		Leibman M, Nesterova N, Altukhov M. Distribution and Morphometry of Thermocirques in the North of West Siberia, Russia[J]. Geosciences, 2023, 13(6): 167.
Barth et al., 2023	3461		Barth, Sophia; Nitze, Ingmar; Juhls, Bennet; Runge, Alexandra; Grosse, Guido (2023): Vector dataset of manually mapped retrogressive thaw slumps from very high-resolution multispectral imagery in the Russian High Arctic between 2011 and 2020. PANGAEA
Runge et al., 2022	1,790		Runge A, Nitze I, Grosse G. Remote sensing annual dynamics of rapid permafrost thaw disturbances with LandTrendr[J]. Remote Sensing of Environment, 2022, 268: 112752.
Zwieback et al., 2018	165		Zwieback S, Kokelj S V, Günther F, et al. Sub-seasonal thaw slump mass wasting is not consistently energy limited at the landscape scale[J]. The Cryosphere, 2018, 12(2): 549-564.
Swanson et al., 2021	1309		Swanson D K. Permafrost thaw-related slope failures in Alaska's Arctic National Parks, c. 1980–2019[J]. Permafrost and periglacial processes, 2021, 32(3): 392-406.
Noerling et al., 2017	87		Noerling C. et al. Permafrost disturbance in Central Yamal along the Bovanenkovo railway line and thermokarst lakes, link to files in different formats. PANGAEA,
Makopoulou2024		15915	Makopoulou E, Karjalainen O, Elia L, et al. Retrogressive thaw slump susceptibility in the northern hemisphere permafrost region[J]. Earth Surface Processes and Landforms, 2024.
MMoceyunas 2024	296	856	
Total RTS feature count	23825	21290	

Data Gap: currently there’s no **centralised** RTS data repository to access all the existing data conveniently in a unified format.

This massive under-utilisation of existing data has severely limited potential RTS studies' scale, statistical significance and deep learning models' generalisation ability

The Arctic Retrogressive Thaw Slumps data set

Scalability

- Update fast changing RTS **time-series**
- Add **new** RTS entries
- Accommodate and manage data **growth**

Interoperability

- Unified standards for **metadata**
- Unified standards for data **formats**
- **Unique** indexing using UID
- Seamless **collaboration** for data contributors
- Easy **access** and **sharing**

Informativeness

- Mandatory key metadata for **reproducibility**
- RTS-present & -absent **digitisations**
- **Peer-reviewed** data sources

RTS-present data (positive)

OBJECTID	17735
CentroidLat	72.75178941
CentroidLon	88.45559342
RegionName	Taimyr
CreatorLab	INitze, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
BaseMapDate	2021-08-06,2021-08-06
BaseMapSource	PSOrthotile
BaseMapResolution	3
TrainClass	Positive
LabelType	Polygon
MergedRTS	<Null>
SplitRTS	<Null>
NewRTS	<Null>
StabilizedRTS	<Null>
UnknownRelationship	<Null>
ContributionDate	2024-06-07
UID	3413dac5-83fa-54fa-ba49-7ed6113f8050
BaseMapID	<Null>
Area	<Null>
Notes	<Null>
Shape_Length	448.012993
Shape_Area	8362.024903

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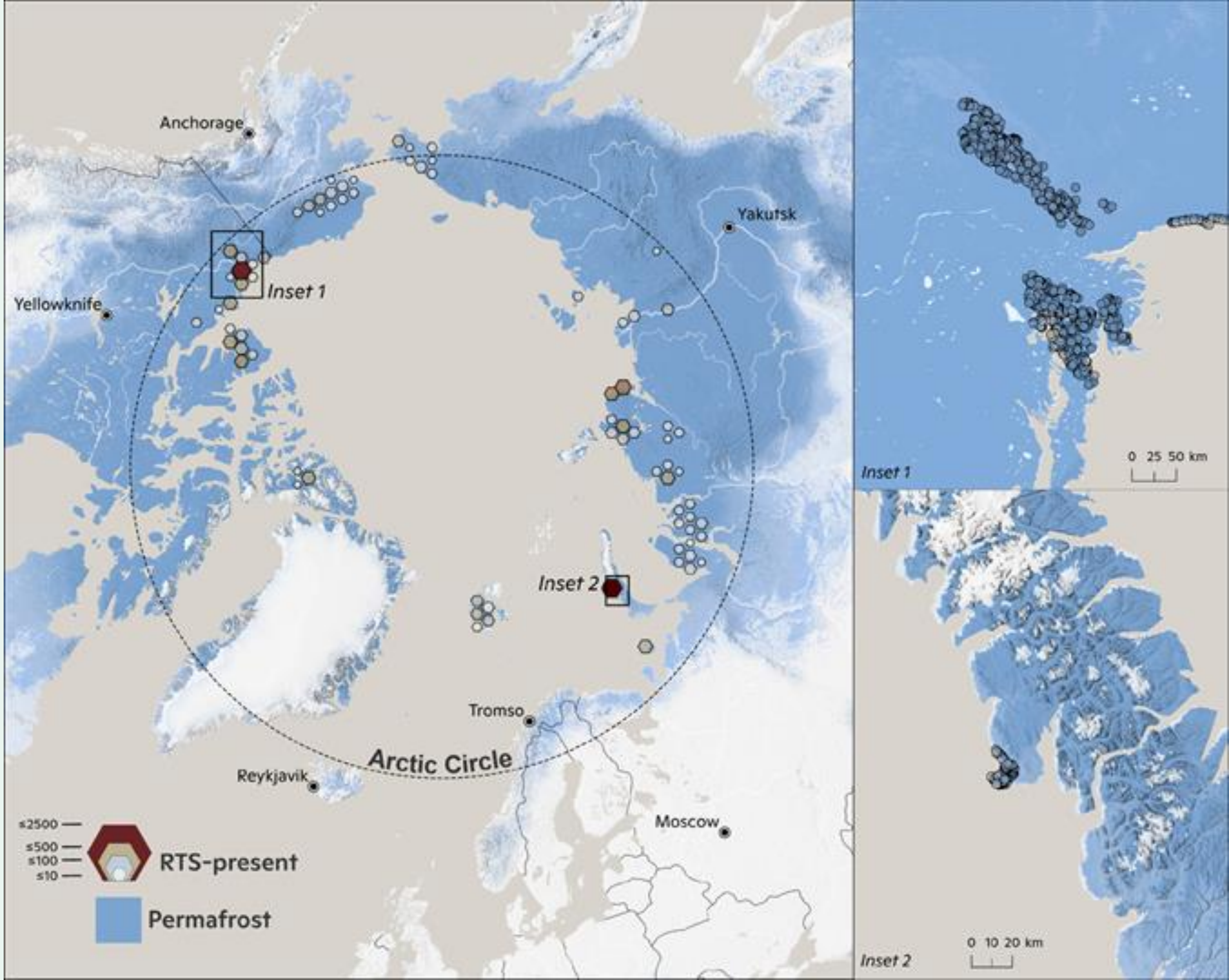
Shape_Length	448.012993
Shape_Area	8362.024903



RTS-absent data (negative)

OBJECTID	35071
CentroidLat	66.0571280181
CentroidLon	61.5220177359
RegionName	Russian Federation
CreatorLab	EMakopoulou, University of Oulu
BaseMapDate	unknown,2021-12-31
BaseMapSource	Esri Basemap
BaseMapResolution	15
TrainClass	Negative
LabelType	Polygon
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BaseMapID	<Null>
Area	<Null>
Notes	<Null>
Shape_Length	1648.818832
Shape_Area	169912.668462

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BaseMapResolution	15
TrainClass	Negative
LabelType	Polygon
MergedRTS	<Null>
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NewRTS	<Null>
StabilizedRTS	<Null>
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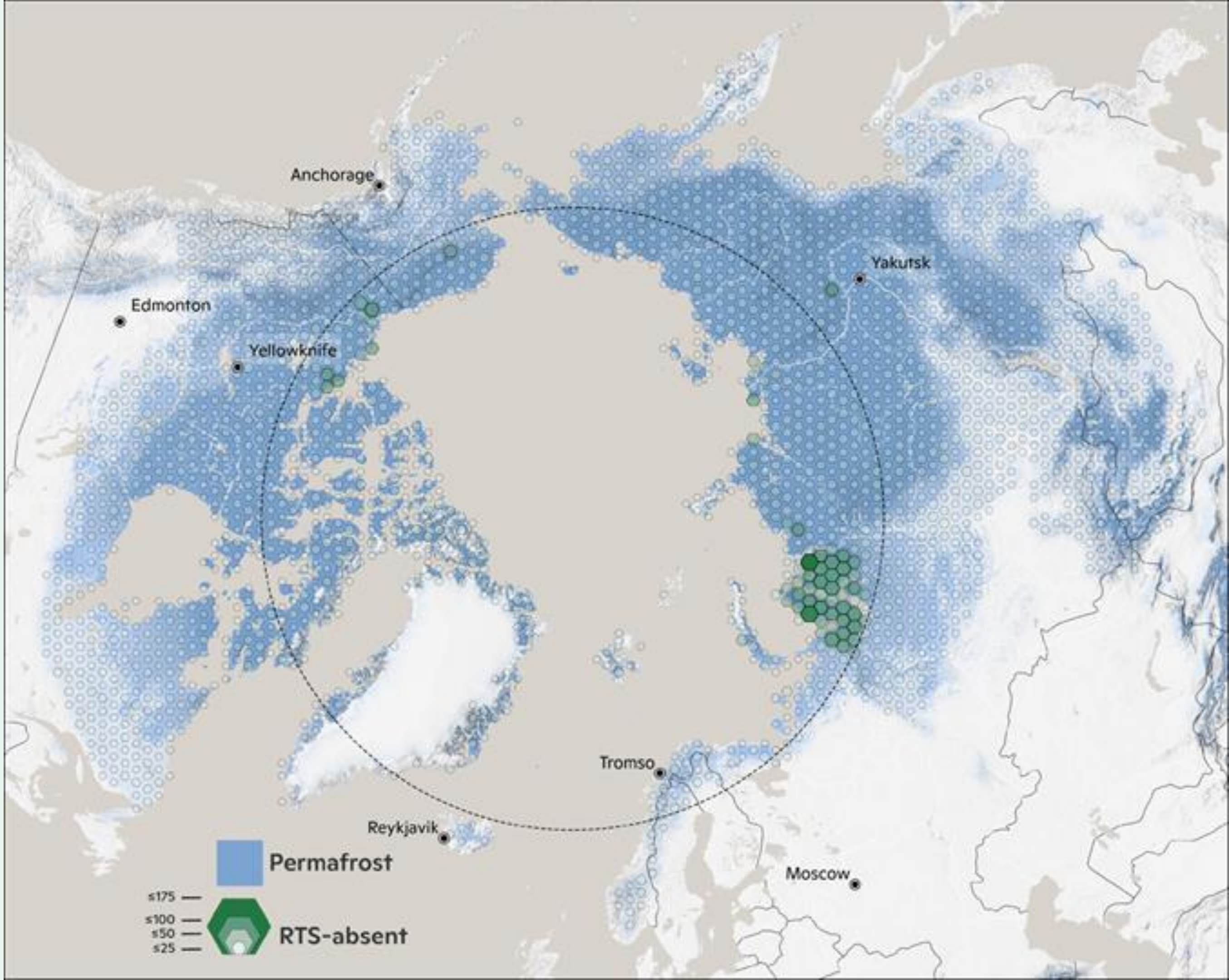

RTS Relations

MergedRTS

CentroidLat	71.1877019018
CentroidLon	79.2472529346
RegionName	Yamal and Gydan Peninsulas, and Northwest Canada (Bank Island, Herschel Island, Horton Delta) and northwest Siberia (Kolguev Island)
CreatorLab	YYang, Woodwell Climate Research Center
BaseMapDate	2017-01-01,2021-12-31
BaseMapSource	Maxar (4m) and Sentinel-2 (10m)
BaseMapResolution	10
TrainClass	Positive
LabelType	Polygon
MergedRTS	f6a888b-1485-5fa8-8382-9f2466f96d01,ac16535d-c38d-53cb-8d01-1f1c2142030a,96a6dca3-ae01-5e75-ad19-96c5ad2143c1,02eb f824-7a25-531c-9e1f-12137a70d588
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NewRTS	
StabilizedRTS	<Null>
UnknownRelationship	<Null>
ContributionDate	2024-06-10
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BaseMapID	<Null>
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Notes	<Null>
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Shape_Area	30818.774861

NewRTS

OBJECTID	2515
CentroidLat	69.19901988
CentroidLon	-138.26652028
RegionName	Yukon Coast, Canada
CreatorLab	JRamage; Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
BaseMapDate	2011-07-13,2011-09-13
BaseMapSource	Multispectral GeoEye-1 and WorldView-2
BaseMapResolution	1.8
TrainClass	Positive
LabelType	Polygon
MergedRTS	<Null>
SplitRTS	<Null>
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StabilizedRTS	<Null>
UnknownRelationship	<Null>
ContributionDate	2024-02-06
UID	df1f1a10-3cd5-59a2-8008-e46e392430de
BaseMapID	<Null>
Area	37307.2
Notes	Kay Point SE
Shape_Length	930.955418
Shape_Area	37495.24222

SplitRTS

OBJECTID	17915
CentroidLat	67.1031747
CentroidLon	-135.57733118
RegionName	Peel Plateau
CreatorLab	INitze, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
BaseMapDate	2022-07-25,2022-07-25
BaseMapSource	PSOrthoTile
BaseMapResolution	3
TrainClass	Positive
LabelType	Polygon
MergedRTS	<Null>
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Area	<Null>
Notes	<Null>
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Shape_Area	12024.253267

23,529

RTS-present data

20,434

RTS-absent data

21

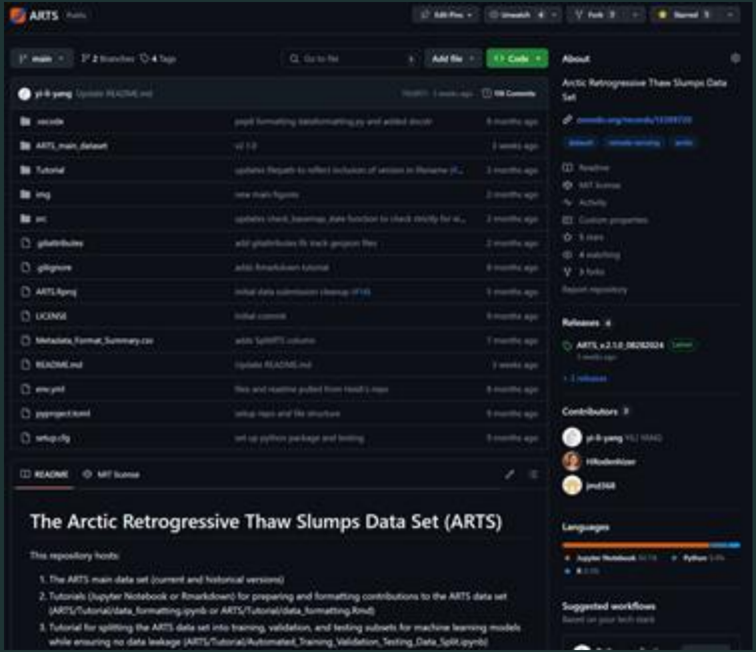
Peer-reviewed, Standalone Source data sets

20+

RTS hot-spots in the Arctic

Archive and Repository

GitHub: Live versions, tutorials, processing codes
https://github.com/whrc/ARTS

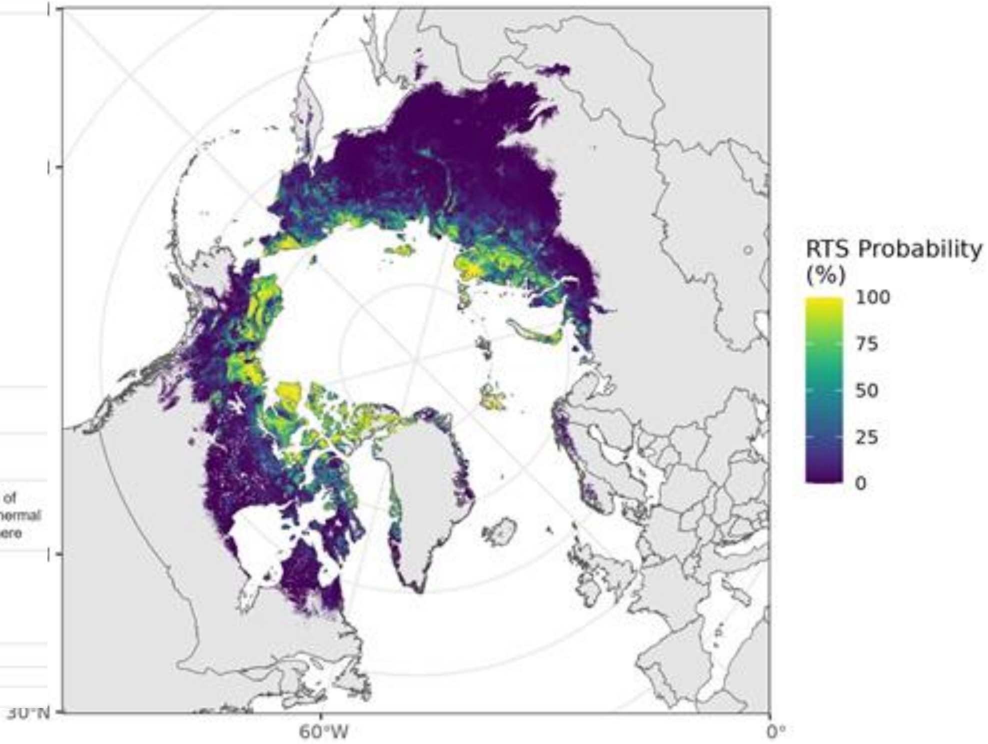


Arctic Data Center
https://arcticdata.io/catalog/view/doi:10.18739/A2PK0738B

Current Efforts using ARTS

Layer Name	Description	Data Source
tmin_min	Annual minimum of the monthly mean low temperature	TerraClimate
tmin_b1	50-year trend in the annual minimum of the monthly mean low temperature	
tmax_max	Annual maximum of the monthly mean high temperature	
tmax_b1	50-year trend in the annual maximum of the monthly mean high temperature	
temp_seasonality	Difference between tmax_max and tmin_min	
precip_max	Annual maximum monthly precipitation sum	
precip_sum	Annual precipitation sum	
precip_b1	50-year trend in precip_sum	
precip_max_b1	50-year trend in precip_max	
swe_max,	Annual maximum snow water equivalent at end of month	
swe_b1	50-year trend in annual maximum snow water equivalent at end of month	
runoff_max	Annual maximum monthly runoff sum	
runoff_sum	Annual runoff sum	
runoff_b1	50-year trend in annual runoff sum	
soil_mean	Annual mean end of month soil moisture	
srad_sum	Annual sum of solar radiation	
suitable_slope	Fraction of pixels between 0 and 20 degrees in 1 km2 aggregated area	CopernicusDEM
suitable_tpi	Fraction of pixels with a TPI between -1 and 1 in 1 km2 aggregated area	
lst_gs_mean	Growing season mean land surface temperature	MODIS
lst_gs_b1	20-year growing season mean land surface temperature trend	
alt	Active layer thickness	NIEER: High-resolution datasets of permafrost thermal state and hydrothermal zonation in the Northern Hemisphere
magt	Mean annual ground temperature	
permafrost_prob	Permafrost probability	
clay	Clay fraction	Soil Grids v2
sand	Sand fraction	
silt	Silt fraction	
ocs	Organic carbon stock	
ice_content	Permafrost ice content	Brown Permafrost Map
hillslope_thermokarst	Thermokarst susceptibility	Olefeldt et al., 2016
yedoma_domain	Yedoma Distribution	Strauss et al., 2021

GBM prediction of RTS susceptibility



Heidi Rodenhizer et al., 2024 in prep

Thank you.