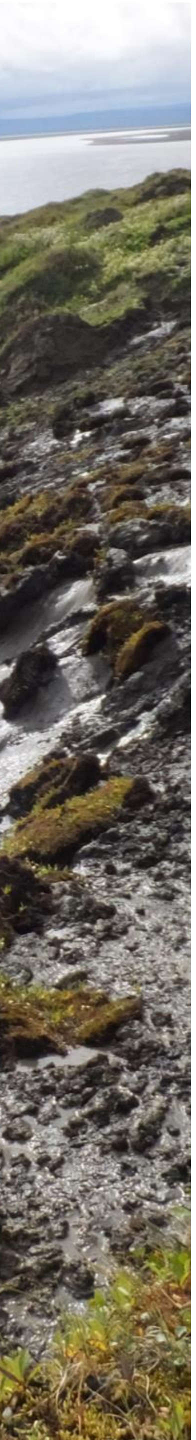


Permafrost Vulnerability From Multiple Essential Climate Variables

Final meeting, Feb 1st, 2024

Dr. Alexandra Runge

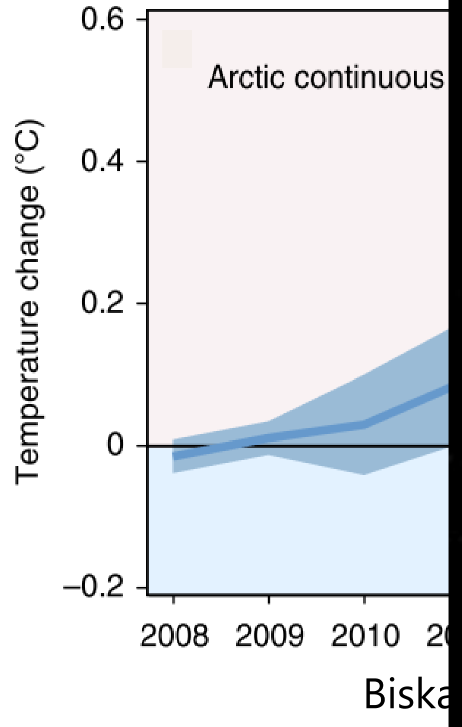
ESA Climate Change Initiative (CCI) Fellowship 2021-2023

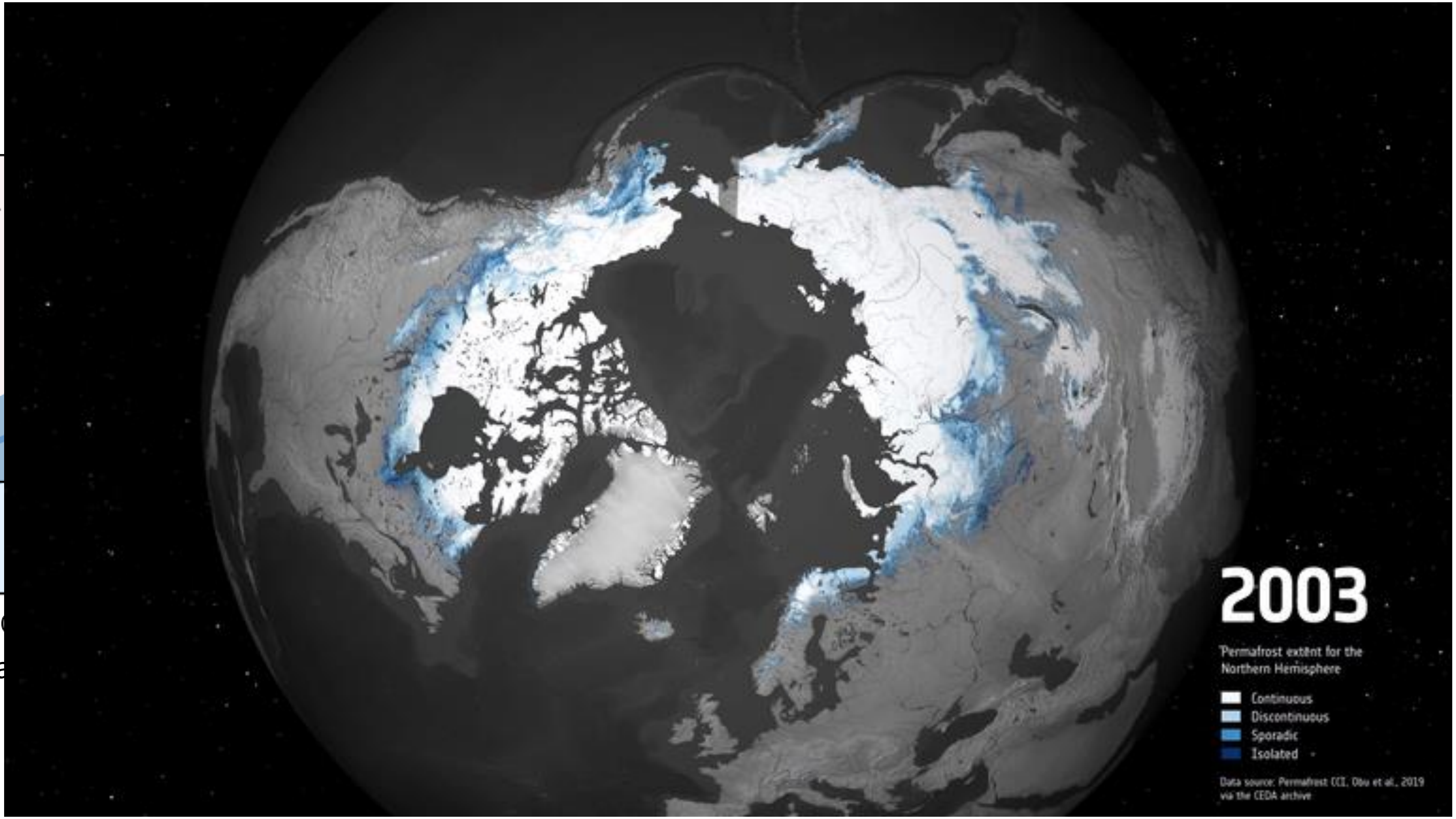
Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany

Agenda

1. Welcome and introduction
2. Project presentation
3. Questions and discussion
4. Closing remarks on fellowship

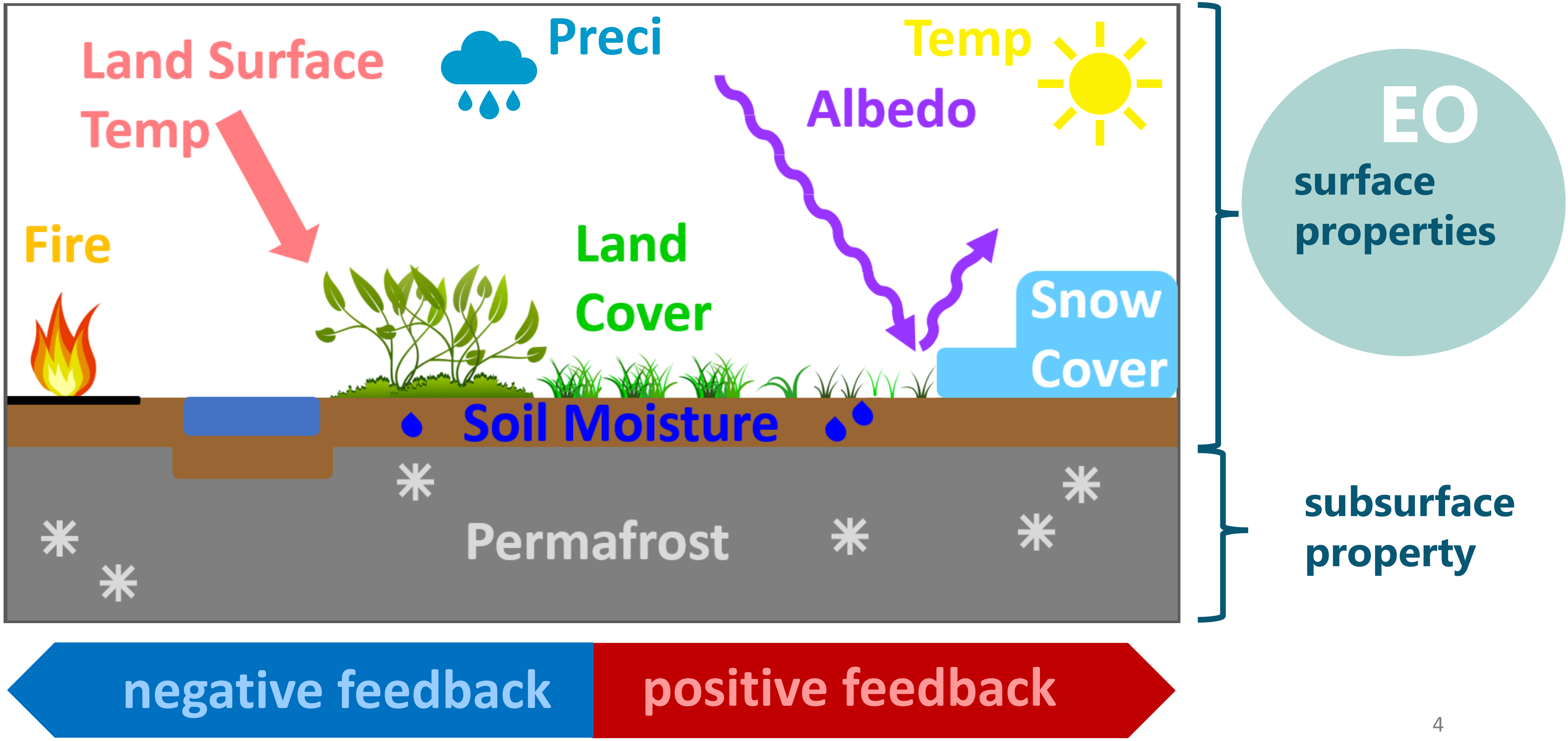
Permafrost is warming at **global** scale





ESA CCI Permafrost data (Obu et al. 2019, Earth-Science Reviews), animation by ESA.

Ground thermal conditions – connected to climate, topography, hydrology, and vegetation



Permafrost vulnerability from combined **surface trends**

Resilience −	PERMAFROST	Vulnerability +
Albedo increase		Albedo decrease
		Fire
Vegetation		Vegetation
LST decrease		LST increase
Snow cover decrease		Snow cover increase
Soil moisture increase		Soil moisture decrease

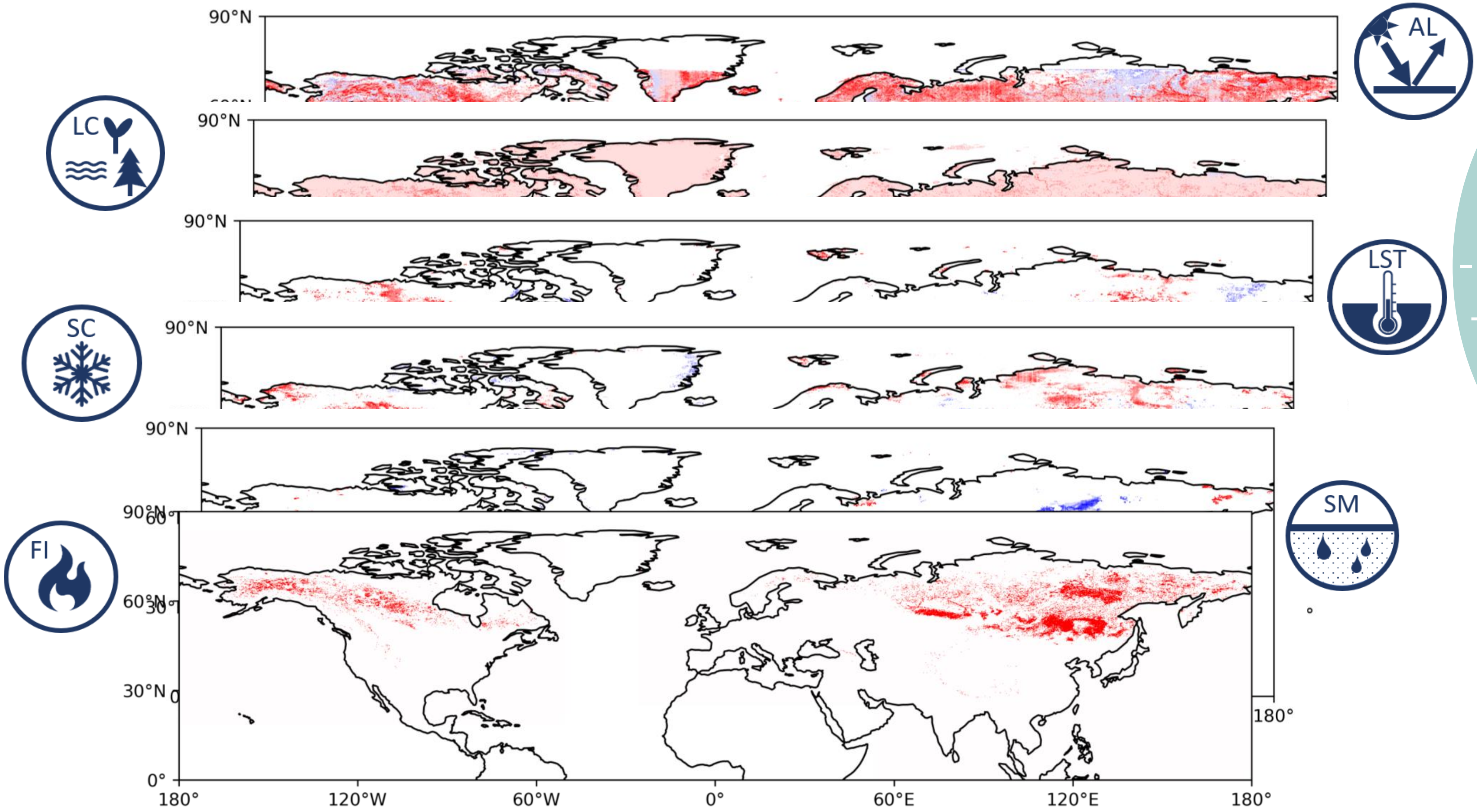
Increase our understanding of the **permafrost-climate dynamics** by analysing **EO data products**
Can we derive information on the **thermal state of permafrost** from **EO-data** of **surface variables**?

1. Consistent processing and **spatiotemporal variability assessment** of the **ECVs**
2. Identify an appropriate **assessment scale**
3. Perform **correlation analysis** and **PCA** to identify **drivers** and **combined impact** of ECVs
4. Set up a **ML framework and model** to perform **permafrost vulnerability mapping** based on ECVs

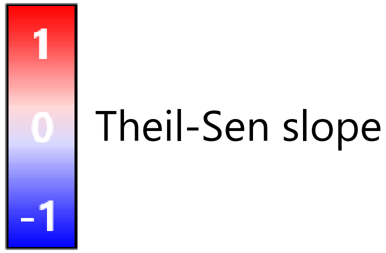
Essential Climate Variables as input

Variable	Parameter	Years	Spatial Resolution	Temporal Resolution	Source
Permafrost	GT 2 m	2000-2019	1 km	annually	ESA CCI (Obu et al., 2021)
Land surface temperature	LST	2000-2018	0.05 deg	daily	ESA CCI (Ermida and Trigo, 2023)
Land cover	NDVI	2000-2020	500 m	16-days	MODIS (MOD13A1 V6.1) (Didan, 2023)
Soil moisture	swvl1	2000-2020	25 km	daily	ERA5 reanalysis (Hersbach et al., 2023)
Snow cover	SCFG	2000-2019	1 km	daily	ESA CCI (Nagler et al., 2021)
Fire	burned area	2001-2019	250 m	monthly	ESA CCI (Chuvieco et al., 2018)
Albedo	ALBB-DH	2000-2020	1 km	10 days	GCOS (Climate Change Service, 2018)
Air temperature	t2m	2000-2020	25 km	daily	ERA5 reanalysis (Hersbach et al., 2023)
Precipitation	tp	2000-2020	25 km	daily	ERA5 reanalysis (Hersbach et al., 2023)

EO-based **Essential Climate Variables** provide consistent **long-term datasets**

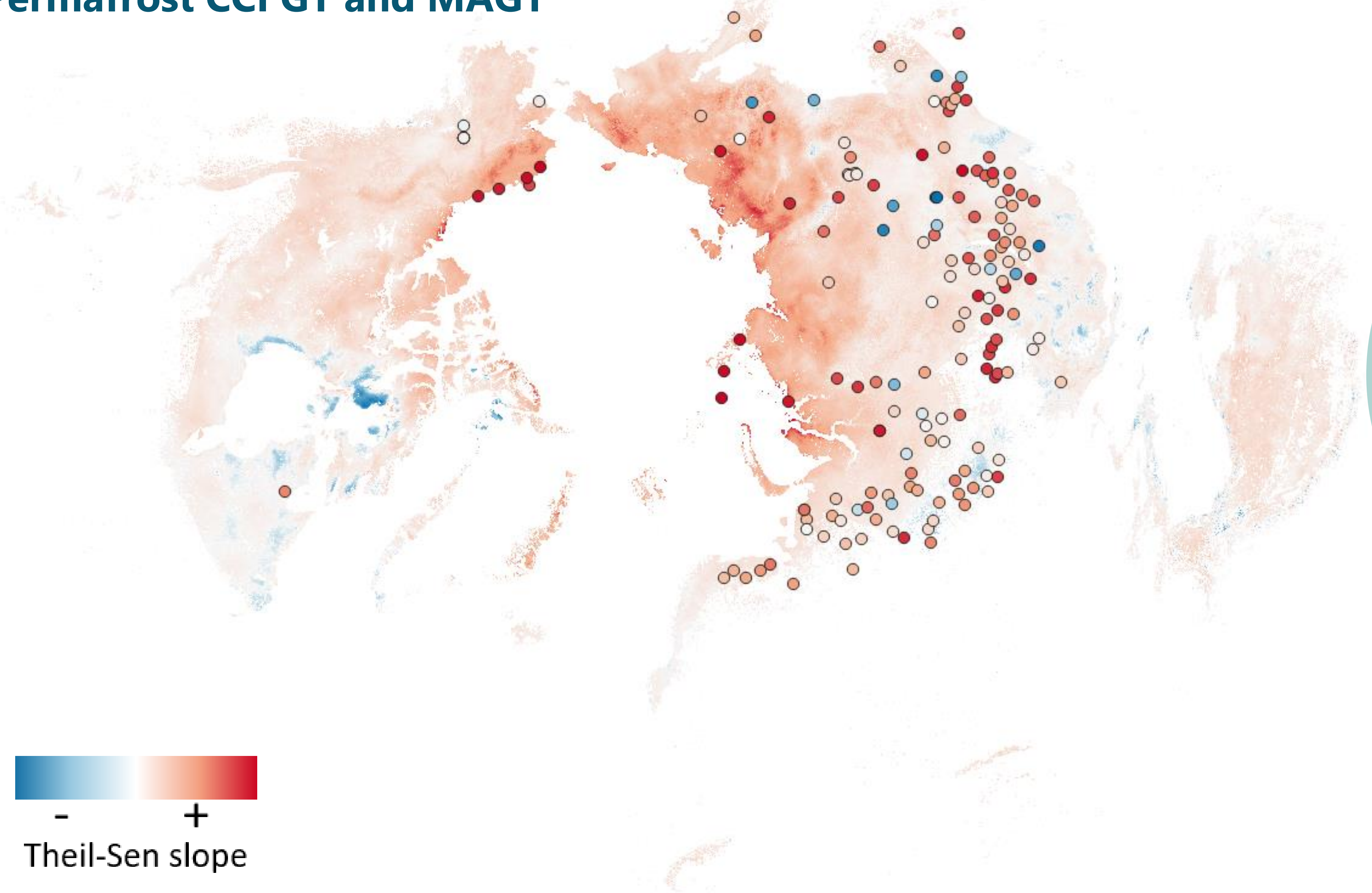


- **Harmonised: annual**
- **2000-2019/2020**
- **stat. significant trends**



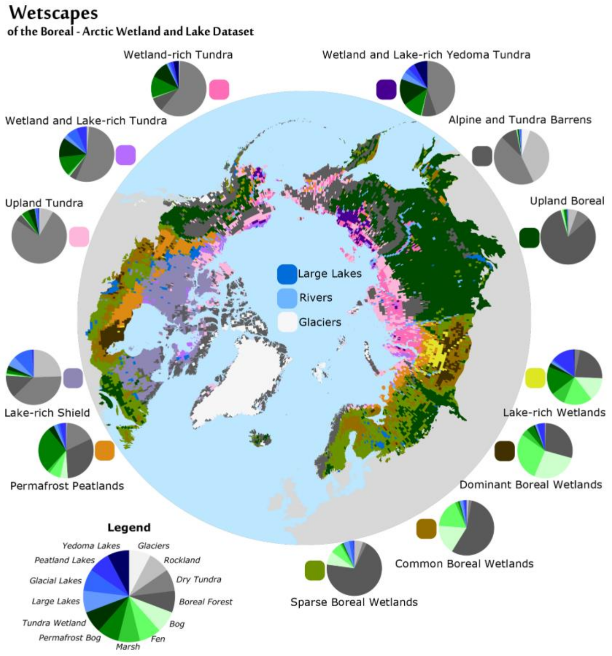
Ground temperature **trends vary** across the **pan-Arctic**

Permafrost CCI GT and MAGT

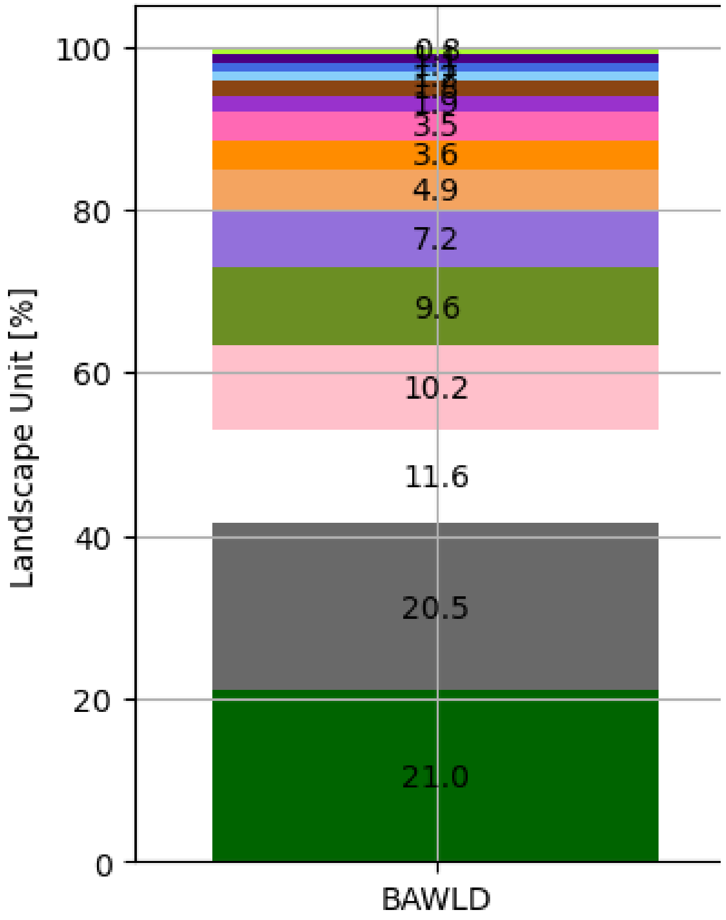


- 166 MAGT
- > 6 years of data
- in recording period 2000-2020
- Theil-Sen slope
- r-Val: 0.52

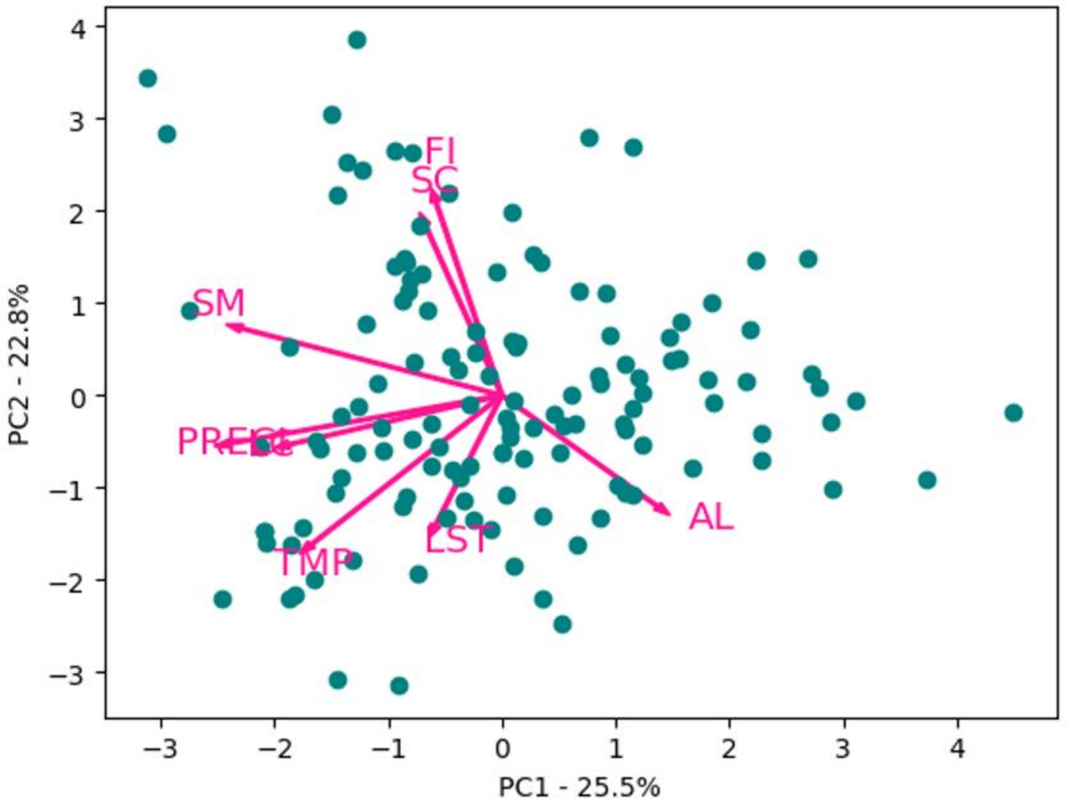
Pan-Arctic landscape units: Boreal-Arctic Wetland and Lake Dataset



- Upland boreal
- Alpine tundra barrens
- Glaciers
- Upland tundra
- Sparse boreal peatlands
- Lake-rich shields
- Common boreal peatlands
- Permafrost peatlands
- Wetland-rich tundra
- Wetland and lake-rich tundra
- Dominant boreal peatlands
- Rivers
- Large lakes
- Wetland and lake-rich yedoma tundra
- Lake-rich wetlands



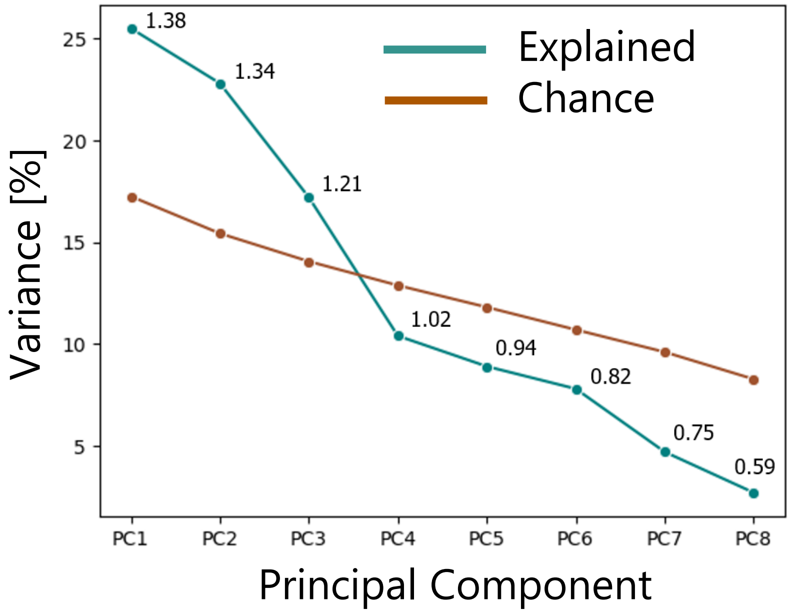
MAGT PCA: **Preci and SM** explain 26%, and **FI** 23%



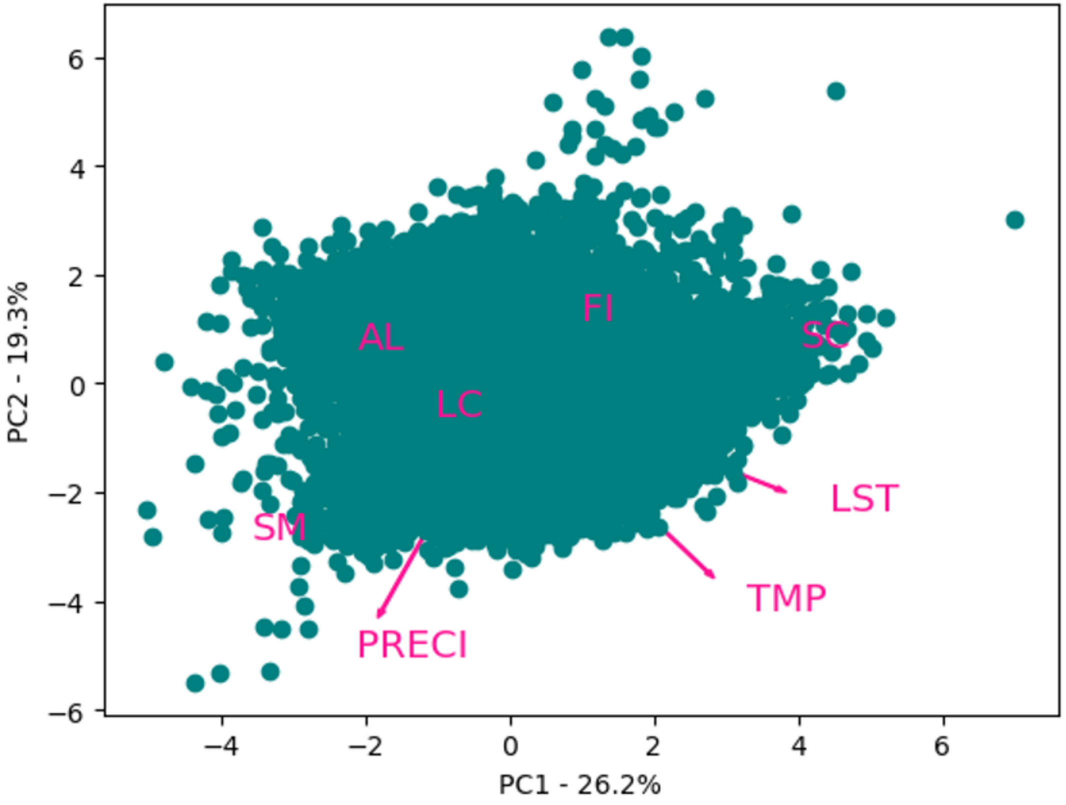
PC1 / PC2

Preci, SM / FI

1000 Permutations



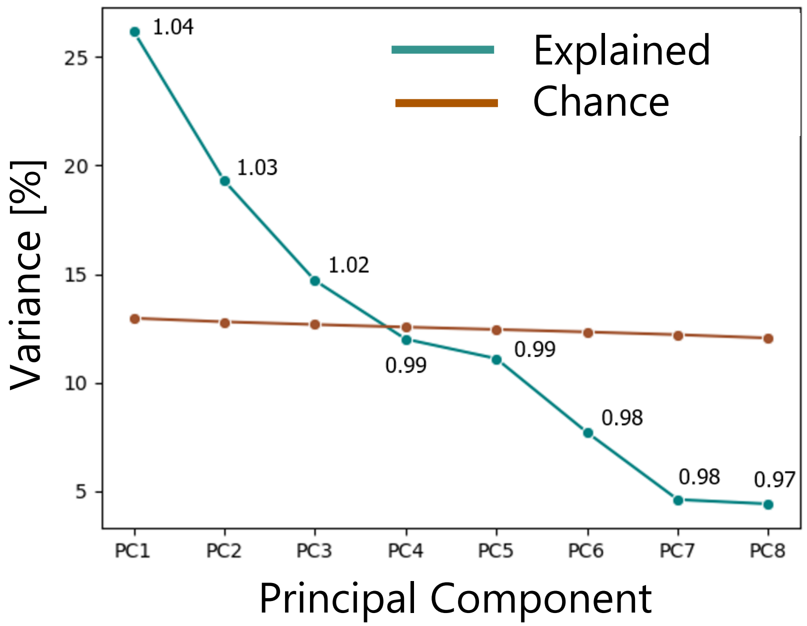
BAWLD PCA: **LST** explains 26%, **Preci and TMP** 19%



PC1 / PC2

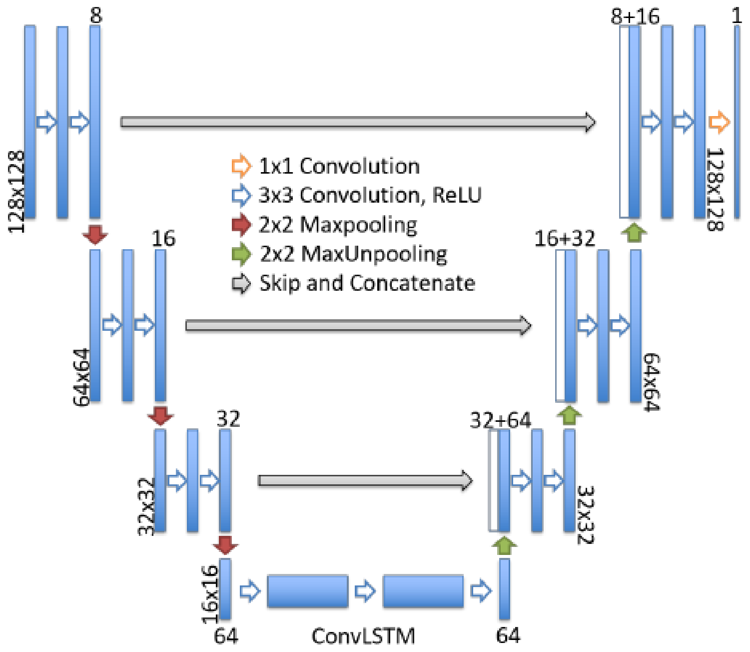
LST / Preci, TMP

1000 Permutations



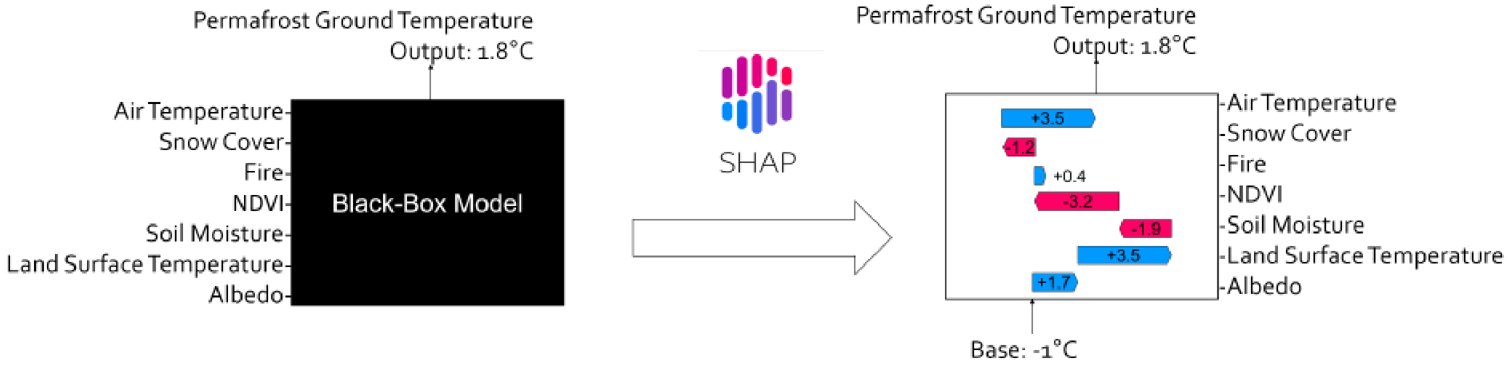
Permafrost vulnerability mapping with ML

DL: U-net and convolutional LSTM



TUM: Adrian Höhl, 3 mths HIDA stipend, ongoing

Feature attribution with SHAP



Discussion

- Lit. review: TMP and Preci drive permafrost thaw (e.g. Douglas et al. 2020, Smith et al. 2022)
  - MAGT: Preci, SM / FI → sparse distribution and representation
  - BAWLD: LST / Preci, TMP → MODIS LST uses in PF model
  - Climate variables > environmental variables
- Biases in assessment
  - MAGT too sparse
  - Time series too short: 20 yrs cannot account for lag period
- ECVs in northern high latitude
  - Calibration and validation is limited
  - Not working with absolute but with trend data

1. Consistent processing and **spatiotemporal variability assessment** of the **ECV**
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✓

MAGT vs BAWLD POI1

↓ **Preci, SM / FI**

↓ **LST / Preci, TMP**

ongoing

Take-away

- **In-situ data is highly valuable → MAGT / GTN-P**
- **Representative sampling is necessary → e.g. BAWLD**
- **Tendencies can be derived for warming of permafrost**

Open questions

- **→ Adrian Höhl and I are working on a deep model and explainable AI approach to identify permafrost vulnerability**
- **Impact of static variables such as topography, ground ice content, soil properties →** topography and global surface water included in ML
- **Lowland vs mountain permafrost?**

Reflection on CCI project

- ESA CCI soil moisture
- ESA CCI land cover
- PF GT vs ALT
- MODIS NDVI vs LAI
- Variable aggregation: seasons

Challenges and problems

- Scope of the project
- Availability and accessibility of CCI data sets

Thank you

Guido Grosse
Annett Bartsch
Adrian Höhl
Konrad Heidler
Bennet Juhls

Anna Maria Trofaier
Frank Martin Seifert
ESA CCI Fellows 2021-23

Permafrost Vulnerability
From Multiple Essential Climate Variables

SC SM LST LC FI AL

AWI

esa