Retrieval of Terrestrial Snow and Cryosphere Parameters From CIMR

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Retrieval of Terrestrial Snow and Cryosphere Parameters From CIMR

Contents:

Development of Cryosphere parameter retrievals for CIMR (CIMR L2PAD)

- Soil freeze/thaw status
- Terrestrial Snow Area
- Snow Water Equivalent

+ Retrieval of snow water equivalent in Copernicus & ESA CCI frameworks

Copernicus Imaging Microwave Radiometer (CIMR)

Mission Objective

Respond's directly to the ***Integrated EU Arctic Policy***

- Climate Change and Safeguarding the Arctic
- Environment Sustainable Development in and around the Arctic
- International Cooperation on Arctic Issues
- Global SST capability

Characteristics

- Conically scanning multi-frequency microwave radiometer
- Single satellite, Observation Zenith angle 55±1.5°
- Loose convoy flight with MetOp-SG(B) ~300s separation
- ~95% global coverage every day, mean 6 hourly-revisit in Arctic Areas
- In Phase C, Launch: 2029

Channels (GHz, all H&V):	**1.4,**	**6.9,**	**10.65,**	**18.7**	**36.5**
Resolution (km):	**≤55**	**10**	**≤10**	**≤5**	**≤5**
NEΔT (K @150K):	**≤0.3**	**≤0.2**	**≤0.3**	**≤0.3**	**≤0.7**
Swath	> 1900km				

Products (Performance TBC, P=Primary, S=Secondary)

P1: Sea Ice Concentration (≤5 km, 5%)

P2: Sea Surface Temperature (10 km, ~0.2 K)

S: Sea Ice Drift (≤25 km, 3 cm/s)

S: Thin Sea Ice Thickness (~40 km, 10%)

S: Snow on Sea Ice

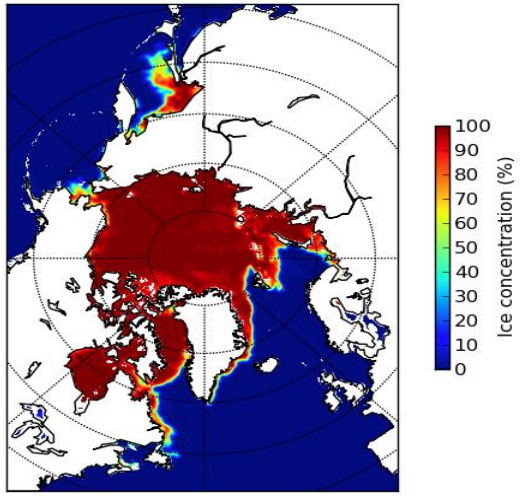
S: Snow Water Equivalent

S: Sea Surface Salinity (~40 km)

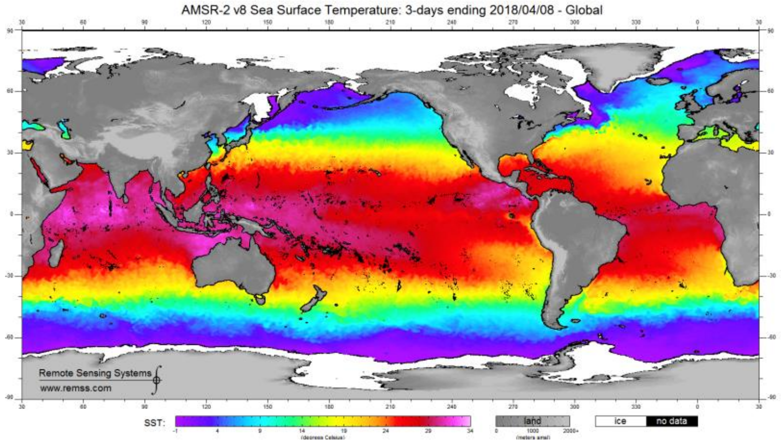
S: Ice Type (≤5 km)

S: Extreme Wind

Additional tertiary products (eg. global soil moisture, water vapour, precipitation rate…)



FMI participates the on-going Phase C studies.
CIMR will be a major breakthrough for SWE retrieval!
~5km spatial resolution

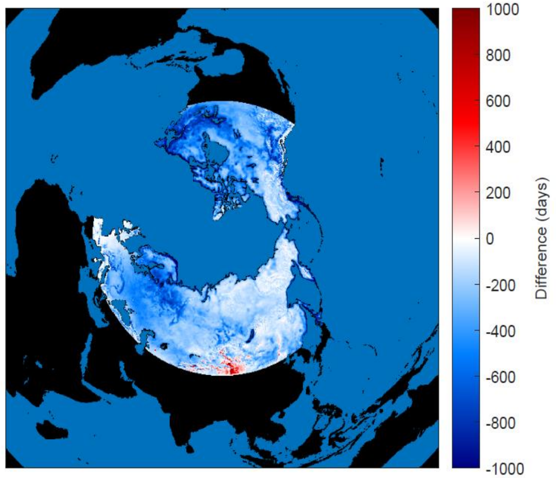


Short intro to ESA CIMR L2PAD algorithm R&D

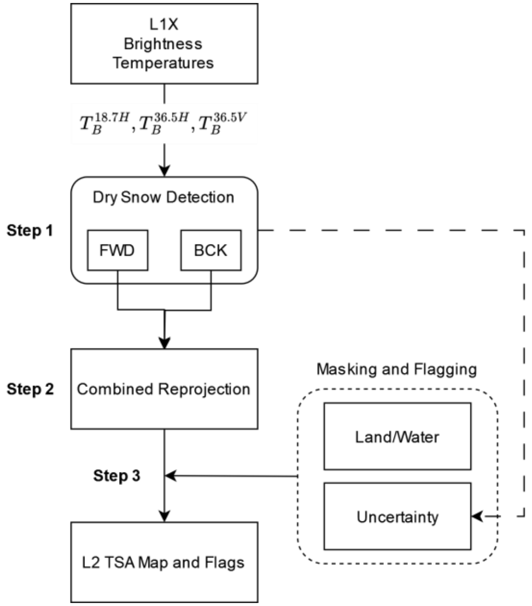
- The CIMR L2PAD algorithm R&D activity will gather state-of-the-art expertise on all the 20+ L2 products to be covered in ESA's L2 G/S (Polar Ocean and Land).
- CIMR L2PAD builds upon past and on-going CIMR studies including CIMR MRC, Apps, SCEPS, MACRAD, and DEVALGO.
- In L2PAD, we continue our focus on Open Source Science (open ATBDs, and open implementation). Algorithms & source codes published on github and as Jupiter Notebooks
- FMI is developing the retrieval algorithms for terrestrial cryosphere:
    - Soil Freeze/Thaw state (Soil F/T)
    - Terrestrial Snow Area (TSA)
    - Snow Water Equivalent (SWE)

Terrestrial Snow Area (algorithm)

- Several existing algorithm available for detection of snow cover, evaluated recently by FMI (Zschenderlein et al. 2023, RSE)
- Typical snow detection approaches utilize 18.7 & 36.5 GHz (+ 89 GHz)
- Baseline algorithm selected for CIMR: EUMETSAT H SAF (H11) dry snow detection approach (Pulliainen et al., 2010) based on Hall et al. (2002) uses **Ku** and **Ka-band** (shows the best global performance for CIMR frequencies)



- Approach by Pulliainen et al. (2010):
  - Introduces updated empirical thresholds, based on approach by Hall et al. (2002)
  - Operational for Europe in EUMETSAT H SAF H11 Snow Status (dry/wet) Product
  - Validated for Northern Hemisphere

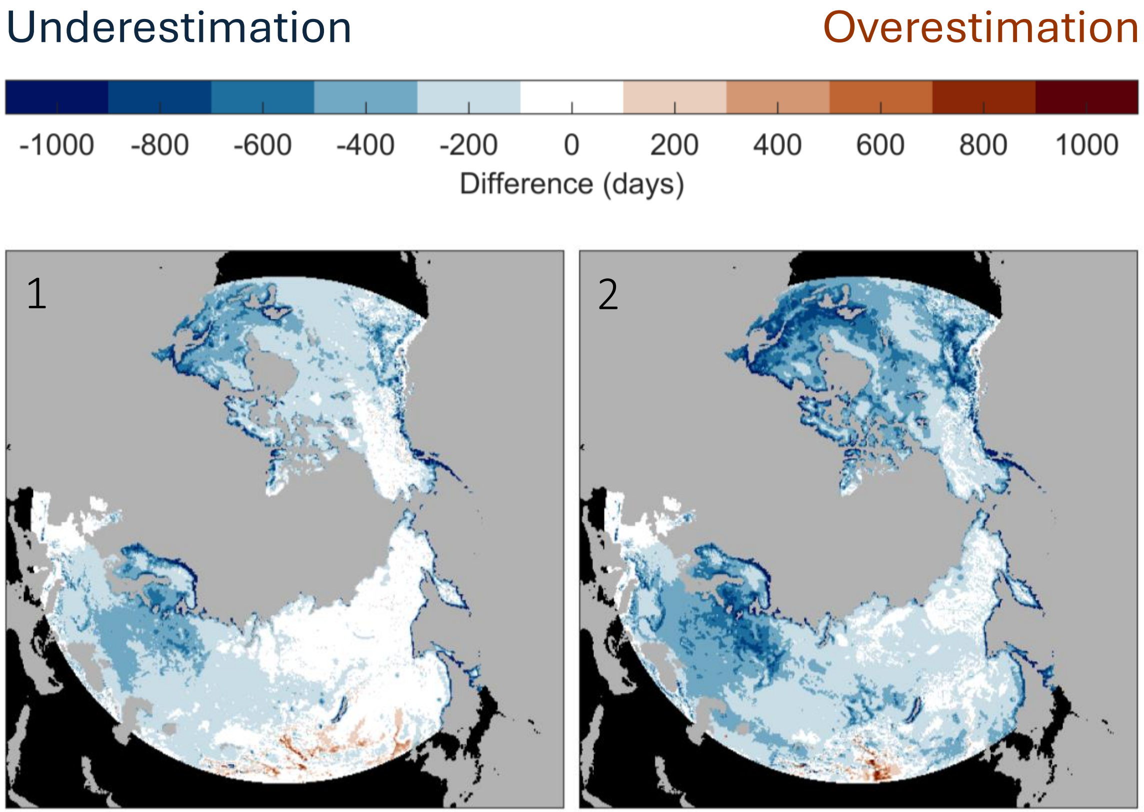


- H-pol TBs sensitive to snow stratigraphy
  → snow layering as indicator for snow presence
- V-pol TBs sensitive to bulk snow properties
  → snow water equivalent retrieval

TSA R&D: Algorithm Comparison

Zschenderlein et al. (2023), RSE

- Long-term comparison of 6 different dry snow detection algorithms
  - Seasonal snow cover (Sep–Feb) above 40°N
  - In situ snow depth data: 30 years (see table)
  - NOAA IMS snow maps: 10 years (see figure)
- Tendency to underestimate snow area
  - Vegetation, snow wetness, shallow snow
  - Discrimination between scattering sources
- TSA impacts the SWE retrieval performance → Improved TSA alg. leads to improved SWE retrievals!



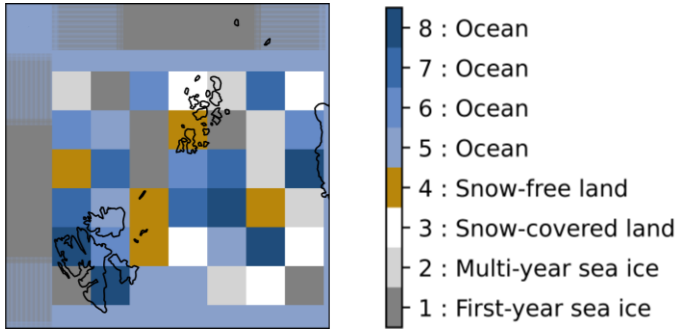
	SSM/I–SSMIS (1987–2017)	*Accuracy*
EUMETSAT H SAF	Grody and Basist (1996)[1]	**82%**
	Pulliainen et al. (2010)[2]	**79%**

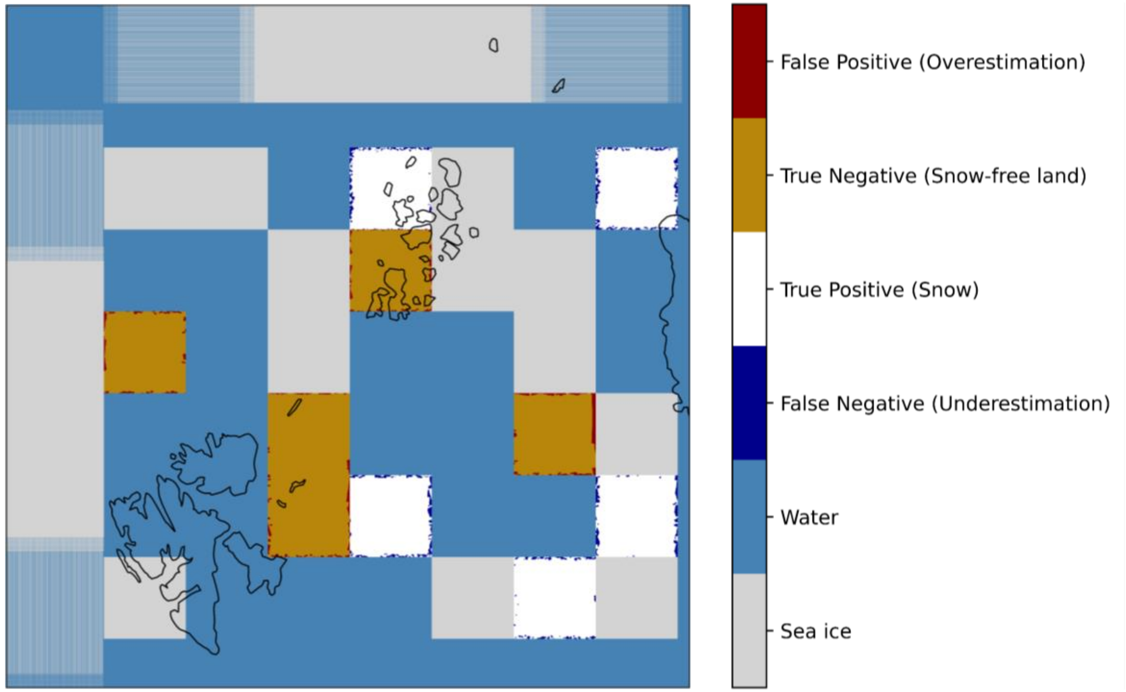
TSA - Algorithm Performance Assessment (CIMR test card)

Radiometric Reference Scenario

Accuracy	95.99%
True positive rate	95.59%
True negative rate	96.38%

- Choice of resampling introduces about ±3% uncertainty
- Optimistic results:
  simulation only of established snowpack and snow-free ground
- Tendency to underestimate
  (higher true negative rate)
- Land-water boundaries challenging
  → Water spill-over corrections needed





Terrestrial Snow Area

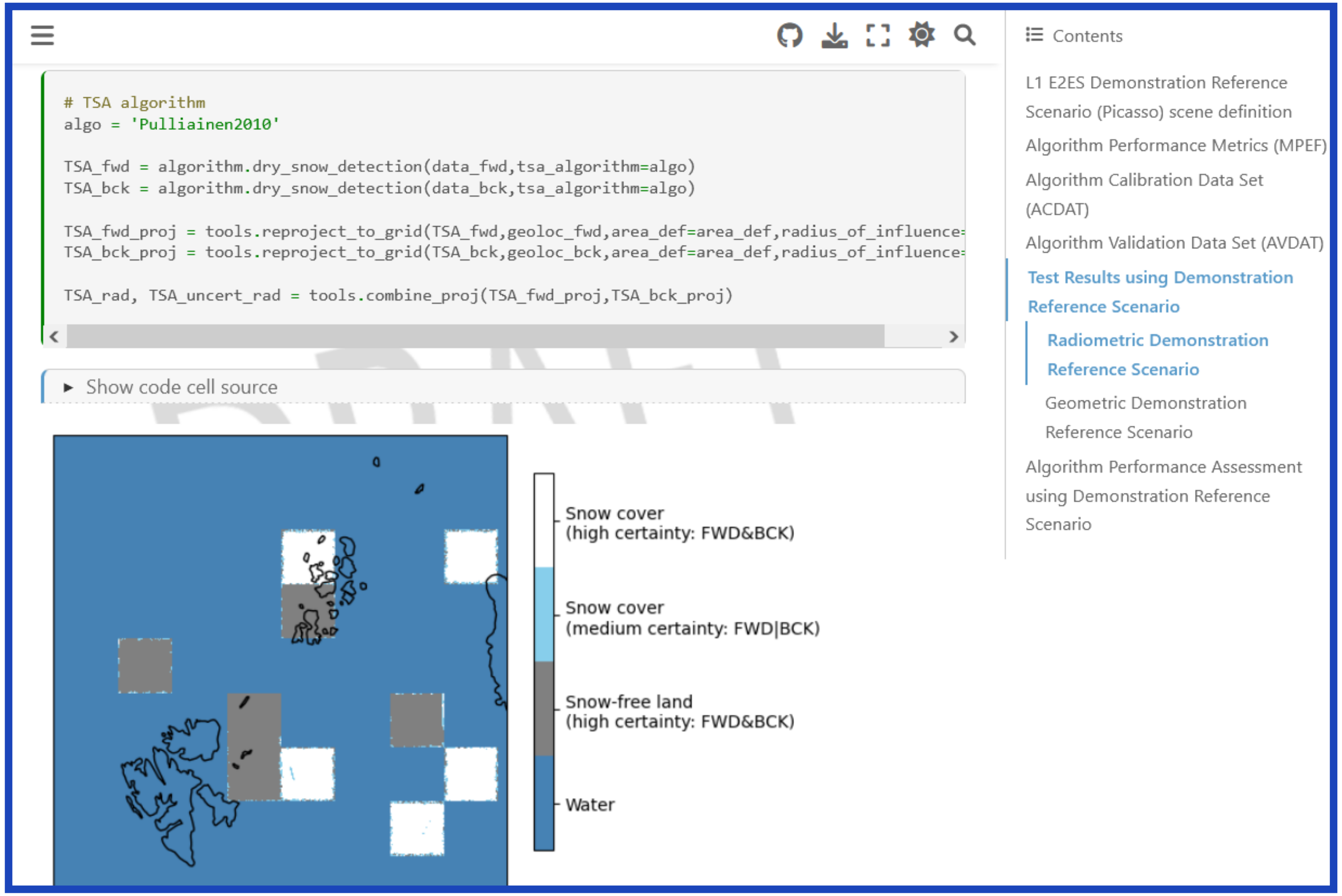
jupyter {book}

Work on CIMR TSA codebase / ATBD (JupyterBook) / JupyterNotebooks:

- **Prototype of Python Codebase**
- **Jupyter Book ATBD**
- **Notebooks for Algorithm Evaluation and Demonstration**

→ transferred to CIMR L2PAD GitHub

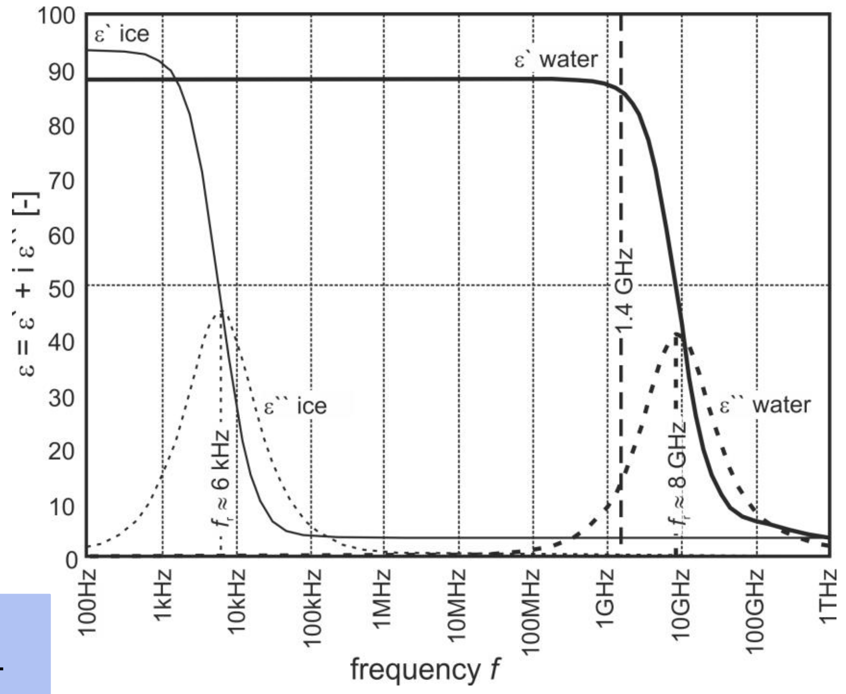
- NetCDF file as output containing TSA variables:
  - TSA
  - Uncertainty Flag
  - Status Flag

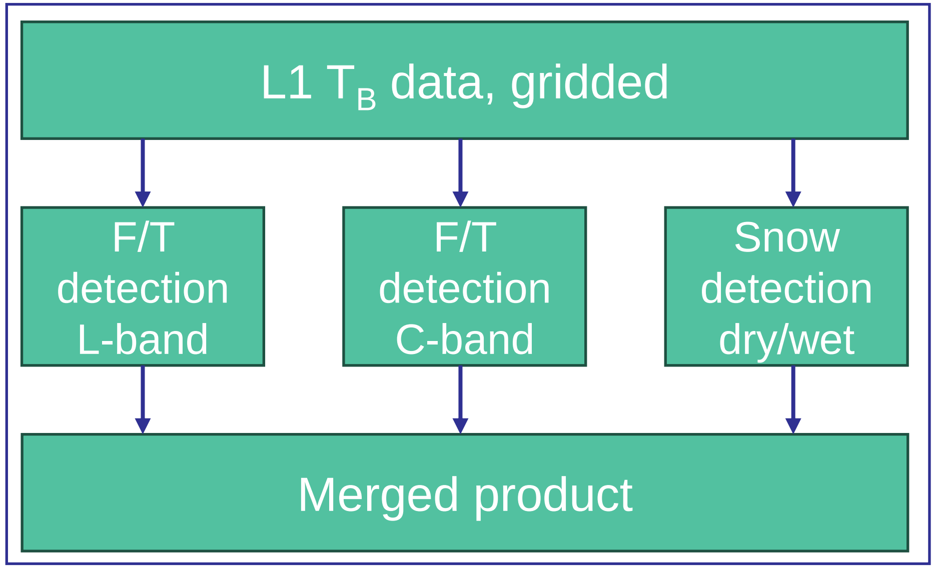


Soil Freeze/Thaw (algorithm)

- The core of the algorithm uses L-band channel, gridded data
  - The algorithm is based on high contrast in permittivity between liquid water and ice
  - Snow and vegetation affect the L-band the least
  - The heritage algorithm from SMOS and SMAP freeze and thaw (Rautiainen et al. 2016; Derksen et al. 2017):
    a) Normalised polarisation ratio (NPR)
    b) Threshold detection, thresholds in relation to the pre-defined frozen and thawed soil references (pixel-wise reference)
    c) Categorized soil state – at a minimum, 'frozen' and 'thawed' states, with a possible third state, e.g., 'partially frozen/thawed.'
- CIMR F/T will include other channels to improve the spatial resolution and to consider the effects of snow cover.

$$NPR = \frac{T_B^V - T_B^H}{T_B^V + T_B^H}$$





SMOS Freeze and Thaw Processing and Dissemination Service

Official SMOS satellite product developed at FMI after launch

Operational, one day latency

Spatial coverage: Northern Hemisphere, gridded to EASE-2 polar projection.

Spatial resolution: 25km x 25km

Temporal coverage: from July 2010 onwards

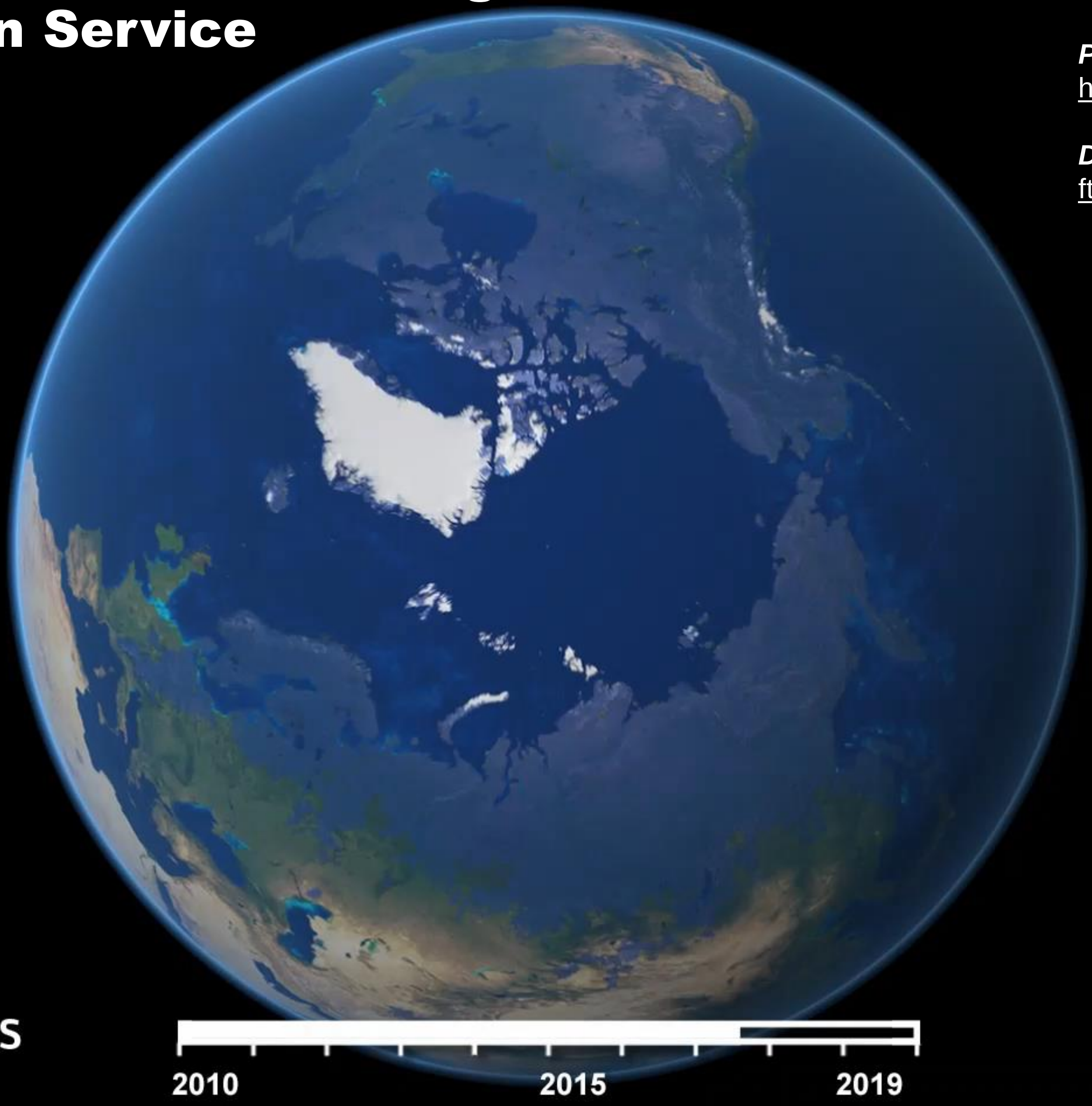
Algorithm based on threshold detection approach

Empirically defined reference signatures for frozen and thawed states

Soil state estimated in three binary levels:

- Frozen
- Partially Frozen
- Thawed

Soil Status from SMOS



Product web page: http://nsdc.fmi.fi/services/SMOSService/

Data download: ftp://litdb.fmi.fi/outgoing/SMOS-FTService/

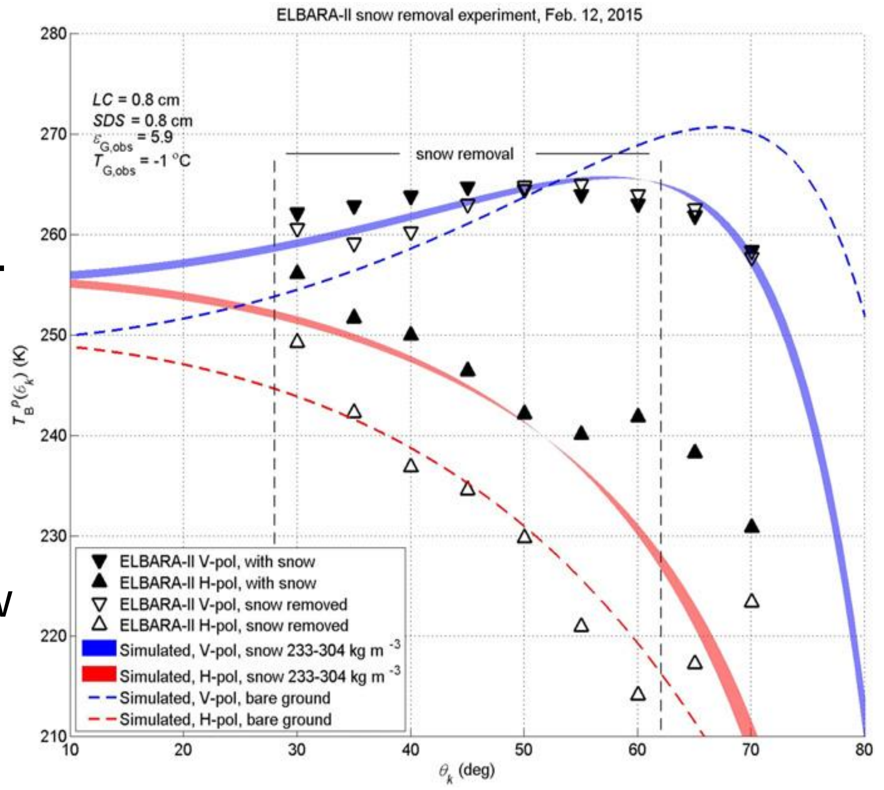
Most challenging targets:

- Dry summer climate
- Barren areas
- Mountains
- Heterogeneous land covers and/or soil types => soil freezing and thawing may vary a lot within the large pixel.

Best performance on cold high latitude areas with moist autumn conditions.

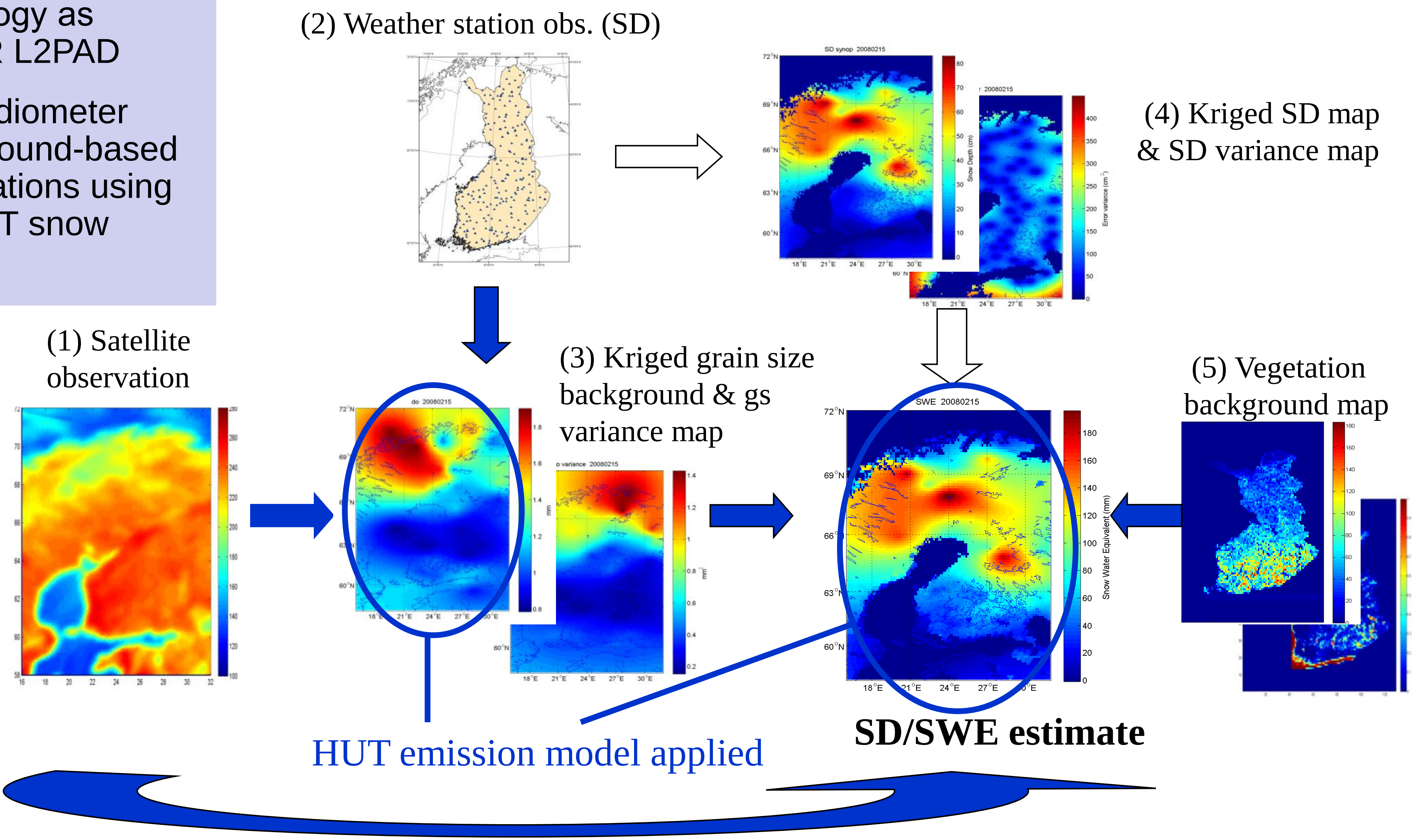
Soil Freeze/Thaw, CIMR added value

- C-band: The landscape Freeze/Thaw state is detected using a similar algorithm.
  - Better spatial resolution; however, the observed signal is largely only from the surface of the target.
  - To be tested if any added value can be achieved and how to combine with L-band
- Snow affects the L-band through refraction and impedance matching. (Schwank et al. 2015; Lemmetyinen et al. 2016)
  - At 50-55º, the effect on V-pol is negligible but significant on H-pol.
  - Dry snowpack changes NPR in a similar way to soil freezing.
  - => Synergy with CIMR TSA to detect snow cover
- Wet snow cover can block even the L-band signal.
  - Combined use with higher frequency channels to detect wet snow
- CIMR will have improved RFI mitigation (at sensor level)



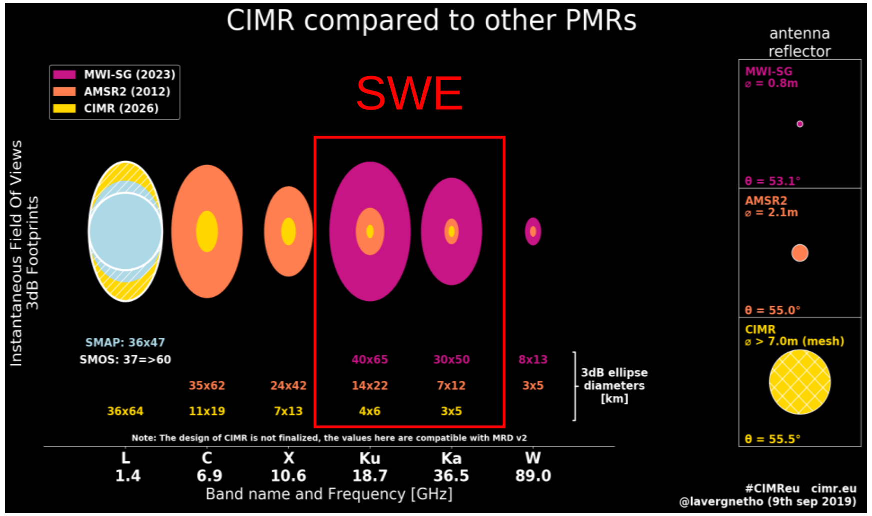
Snow Water Equivalent (algorithm)

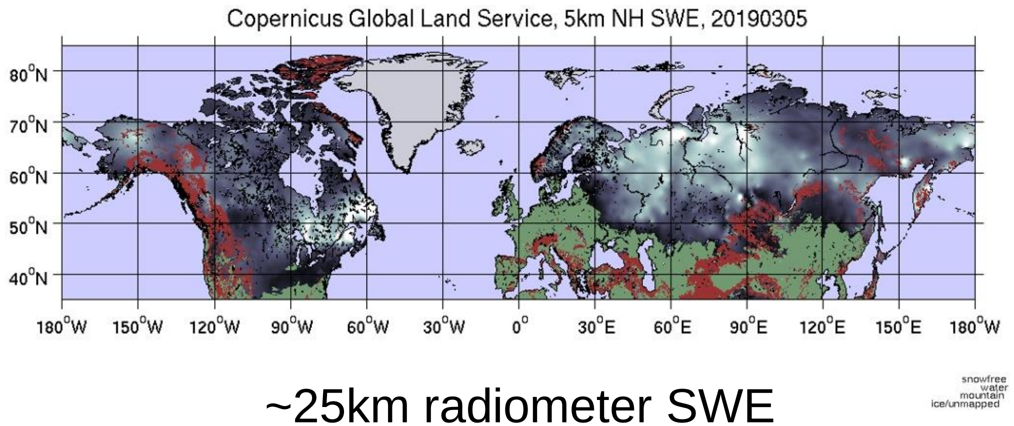
- “GlobSnow” methodology as starting point for CIMR L2PAD
- Passive microwave radiometer data combined with ground-based synoptic snow observations using the semi-empirical HUT snow emission model
- Ka/Ku band
- Coarse resolution
- Non-mountainous
- Terrestrial domain
- CIMR L2PAD R&D: satellite-only retrieval?



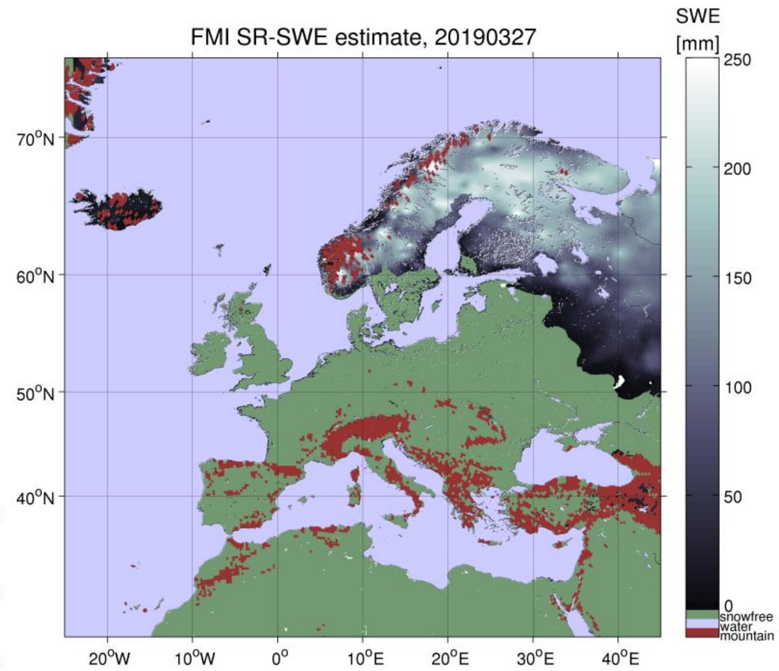
SWE retrieval with CIMR - spatial resolution

- *Current SWE retrieval applies SSMIS data with ~25km spatial resolution*
- *CIMR will be a game changer with ~5km spatial resolution (Ku/Ka bands)!*





~25km radiometer SWE

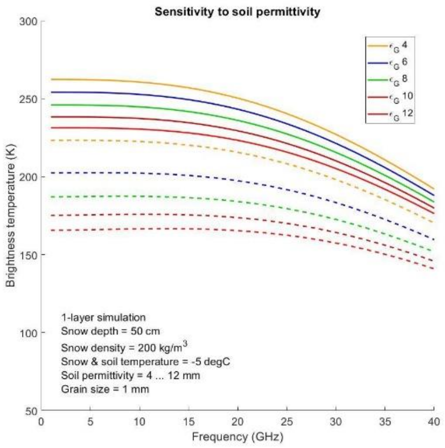


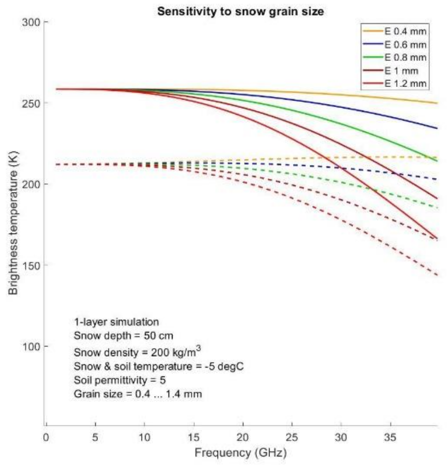
Simulated ~5km radiometer SWE

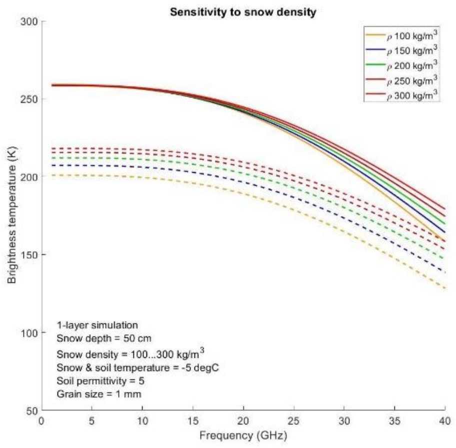
SWE retrieval with CIMR - frequencies

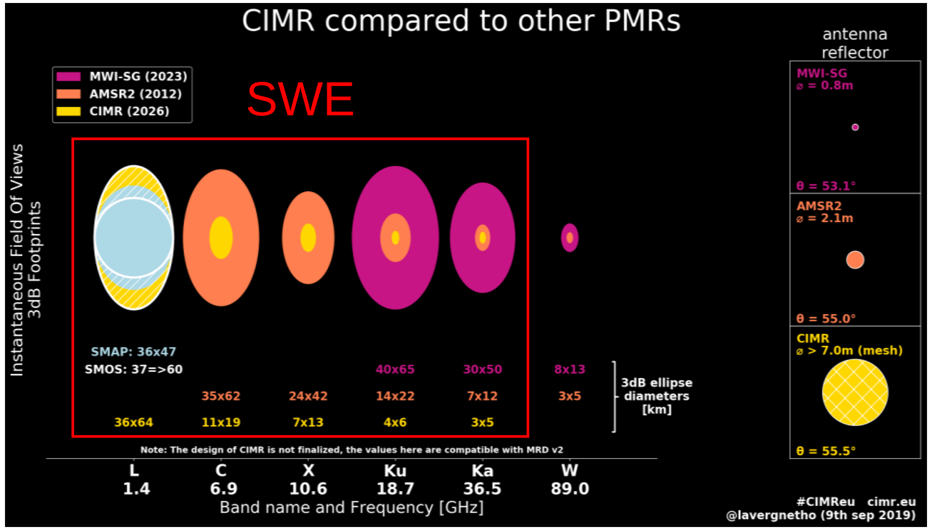
- *Current SWE retrieval applies Ku & Ka-band data*
- *The goal is to apply full range of CIMR frequencies for SWE retrieval, some potential approaches:*
    - *L- & C-band data utilized to estimate ground characteristics (earlier studies done with SMOS data)*
    - *X- to Ka-band data utilized to estimate/constrain snow density and microstructure (various approaches possible)*

  -> this additional information can be used with the existing "GlobSnow" SWE retrieval framework





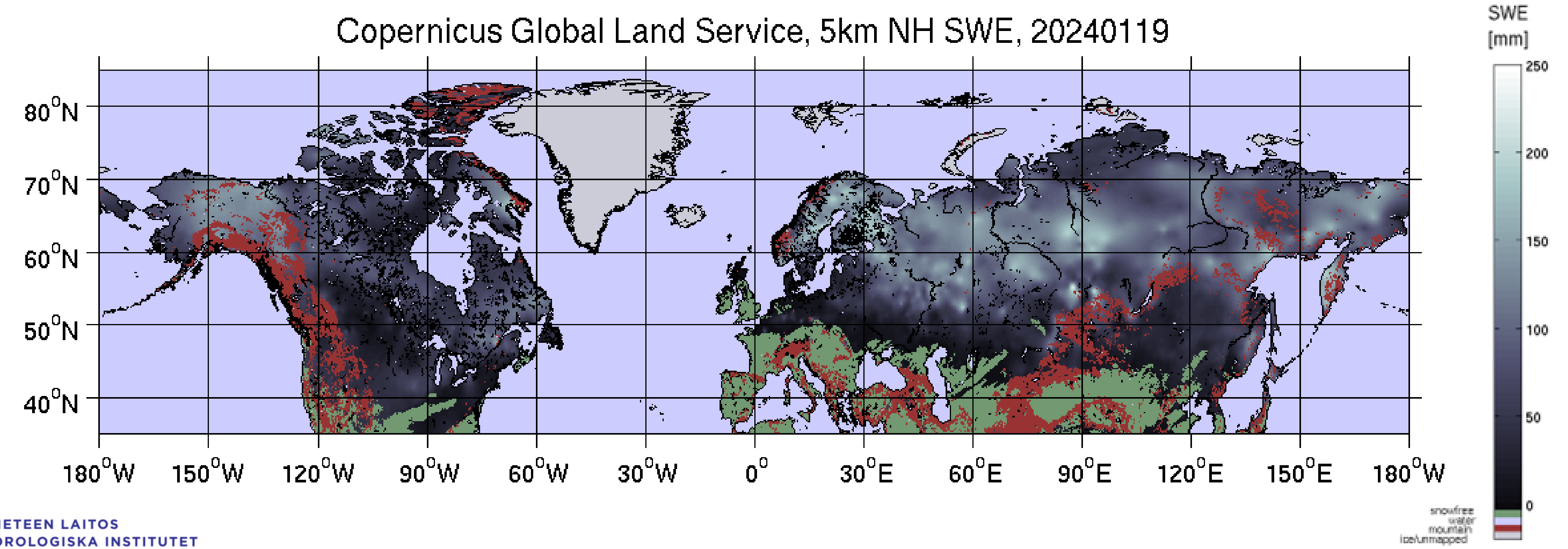




Snow Water Equivalent
(Copernicus Land Monitoring Service + C3S coming)

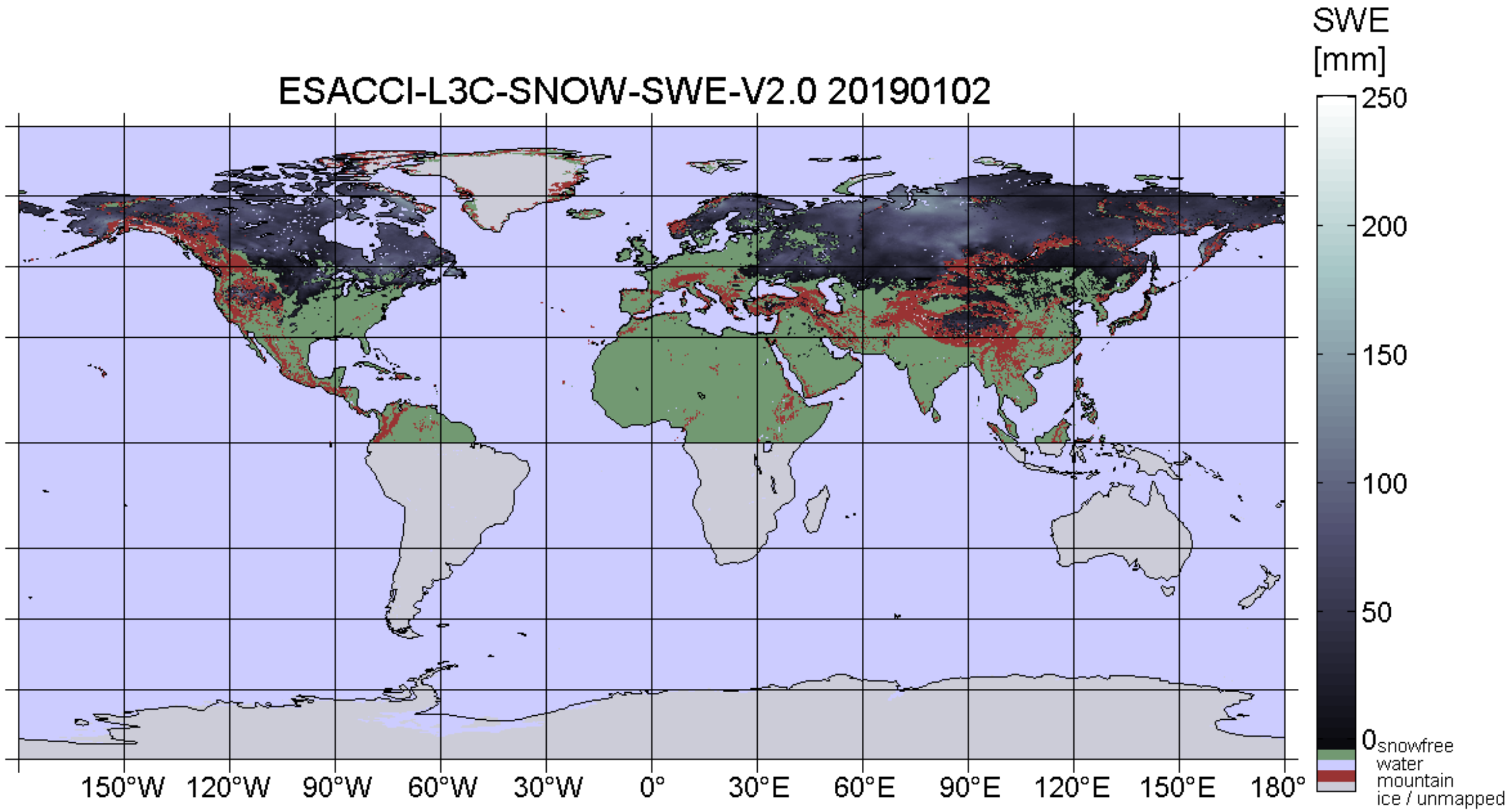
Copernicus
Europe's eyes on Earth

- **Copernicus Global Land service - Daily Northern Hemisphere SWE (5 km resolution)**
- PMW retrievals augmented using optical EO-data & NOAA IMS snow mask
- 0.05° (~5km) NH lat/lon grid, daily SWE product (super-sampled from coarse resolution PMW data)
- Mountains, glaciers and icesheets masked out (snow on land)



ESA Snow CCI – v3.0 SWE Climate Data Record

- Climate Data Record of Snow - variable:
  - Snow water equivalent (SWE)
  - Uncertainty estimate (STD of SWE estimate)
  - Retrieval algorithm:
    - Takala et al. 2011
    - Luojus et al. 2021
    - Venäläinen et al. 2023
    - Zschenderlein et al. 2023
- Time series: January 1979 – June 2022
- Spatial:
  - Coverage: Northern Hemisphere
  - Grid size: 0.10°
  - Projection: Geographical (lat/lon)
  - Datum: WGS 84
- Temporal:
  - Resolution: 1 day
  - Aggregation: Monthly (+ bias correction)
    Pulliainen et al. 2020 *Nature appr.*
- File:
  - Representation: 32 bit float (SWE: 0-500 mm)
  - Metadata: Land/sea mask, SWE uncertainty
  - Format: NetCDF4, CF-v1.9



SWE product (CDR) will be added to C3S in 2025!

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Environment and Climate Change Canada

esa

snow cci

ESA Snow CCI - SWE climate data record

Basis for a recent 'Nature' snow mass reconstruction

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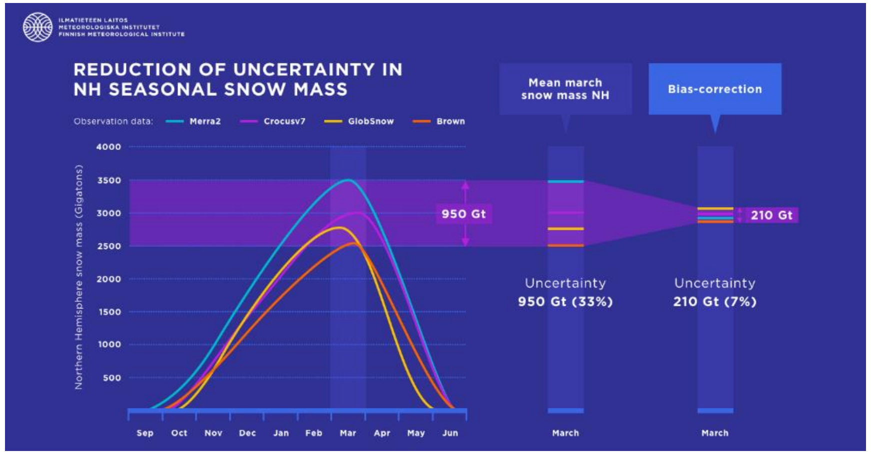
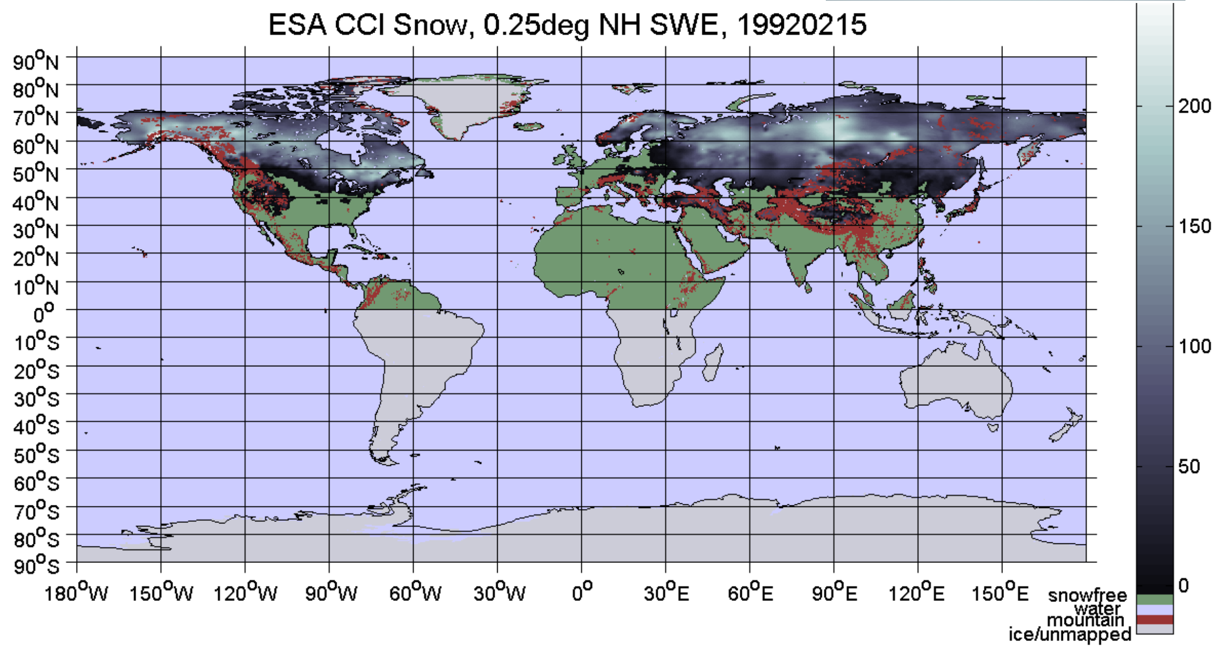
Environment and Climate Change Canada

- Snow water equivalent (SWE) CDR
  - January 1979 - May 2023
  - Northern Hemisphere 0.25°/0.10° (lat/lon)
  - Daily & monthly products
- Passive microwave radiometer data combined with ground-based snow observations
- Most accurate reconstruction of the satellite-era snow mass:
  - **Pulliainen et al. 2020 Nature**
- **Large regional variations in NH snow mass!**
- **CIMR** is crucial to extend the long-term climate data record





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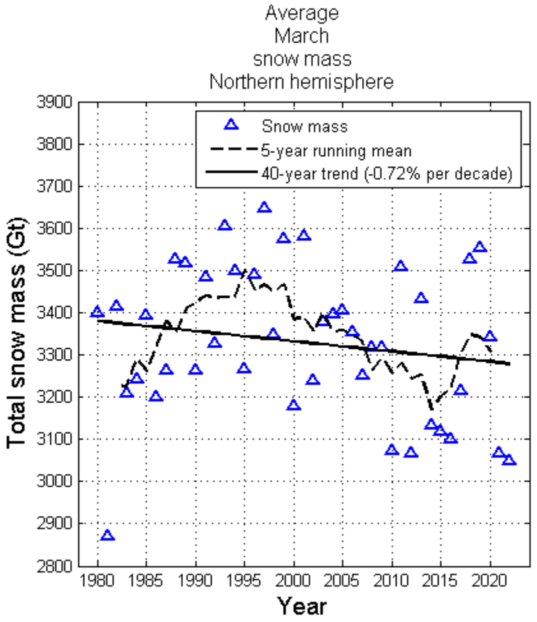
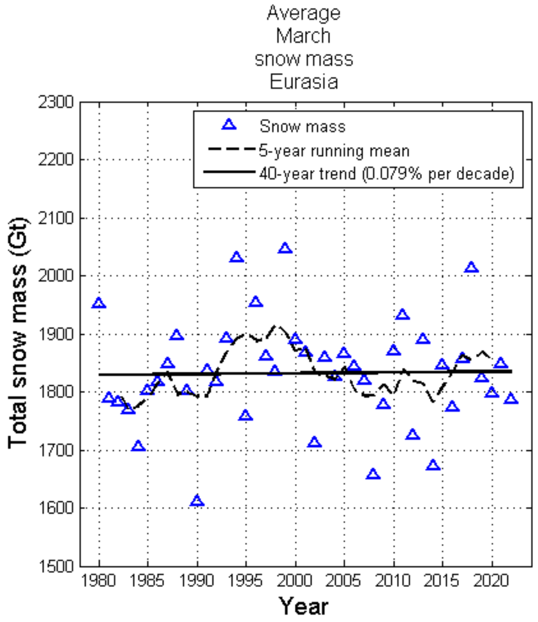
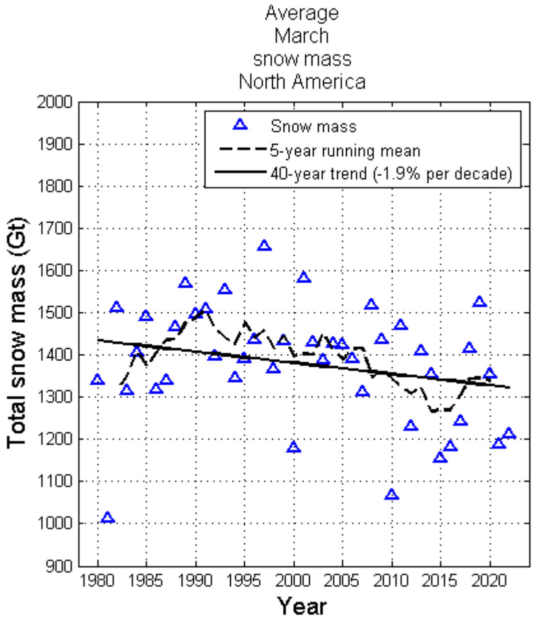
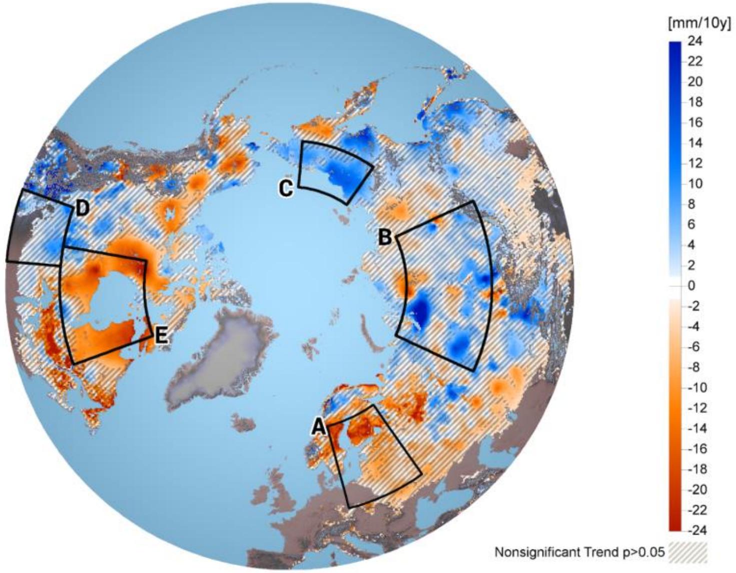
ESA Snow CCI, average March snow mass on northern hemisphere 1980 – 2022

- Regional differences are strong, Negligible overall trend in Eurasia, Declining trend in North America
- Overall -> **NH snow mass shows a slightly decreasing trend**









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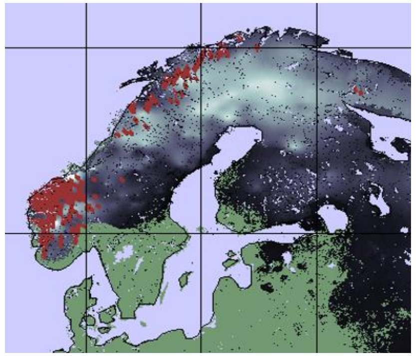
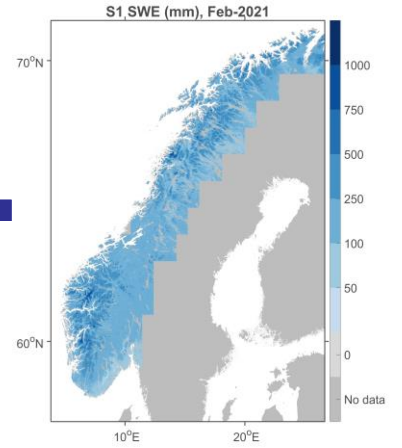
ESA SnowPower demo project

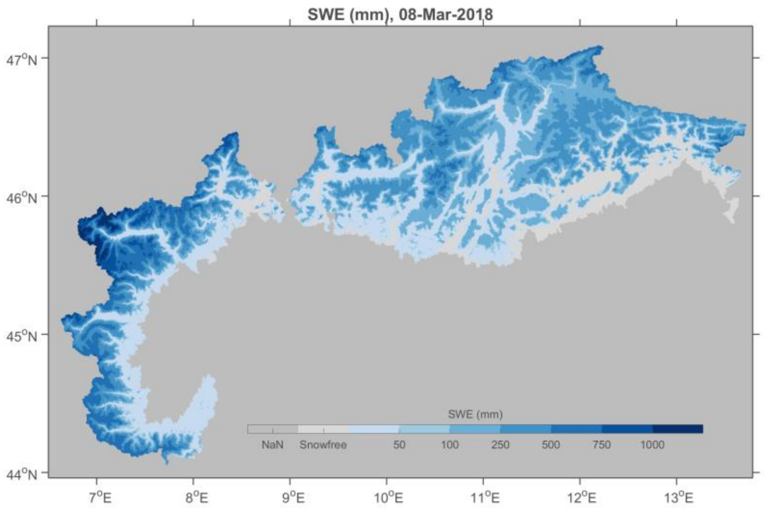
- ESA demonstration project (2024-2025, ESA BASS progamme)
  utilization of SAR-based SD/SWE estimates for hydropower optimization
- Project investigates the potential to **combine PMW & SAR-based snow retrievals for mountains** & to operationalize the methodology
- Sentinel-1 based SD/SWE production **system runs operationally for the Alps!**
- Demo project with an **active end user interaction!**

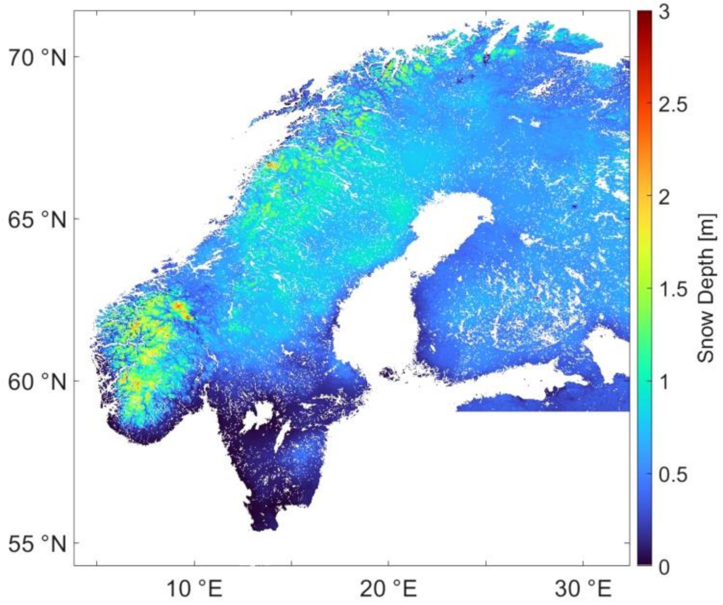
PMW SWE



SAR-based mountain SD







Merged PMW + SAR SWE

detect more.

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Summary

- **The CIMR L2PAD project works on developing the L2 retrieval algorithms and G/S processors for the upcoming CIMR mission (launch ~2029)**
- **L2PAD has a strong focus on Open Source Science. ATBDs, algorithms & source codes published on github and as Jupiter Notebooks**
- **FMI is developing the retrieval algorithms for terrestrial cryosphere:**
  - Soil Freeze/Thaw state (Soil F/T)
  - Terrestrial Snow Area (TSA)
  - Snow Water Equivalent (SWE)

Key result in observed NH snow mass trends (ESA CCI results):

- We can observer a slightly decreasing trend for March NH Snow mass for 1980-2022, driven by changes in North America