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Long-term snow observations from satellite for new operational C3S cryosphere and hydrology services

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Introduction

Seasonal snow plays an important role in the Earth's hydrological and climate systems

- ❑ Snow water equivalent (SWE) is a measure indicating the accumulated snow mass on land surfaces
- ❑ Snow that accumulates during the winter season plays a significant role in groundwater recharge

➢ **The Copernicus Climate Change Service (C3S) offers new services for cryosphere and hydrology by providing operational long-term data records of Snow Water Equivalent**

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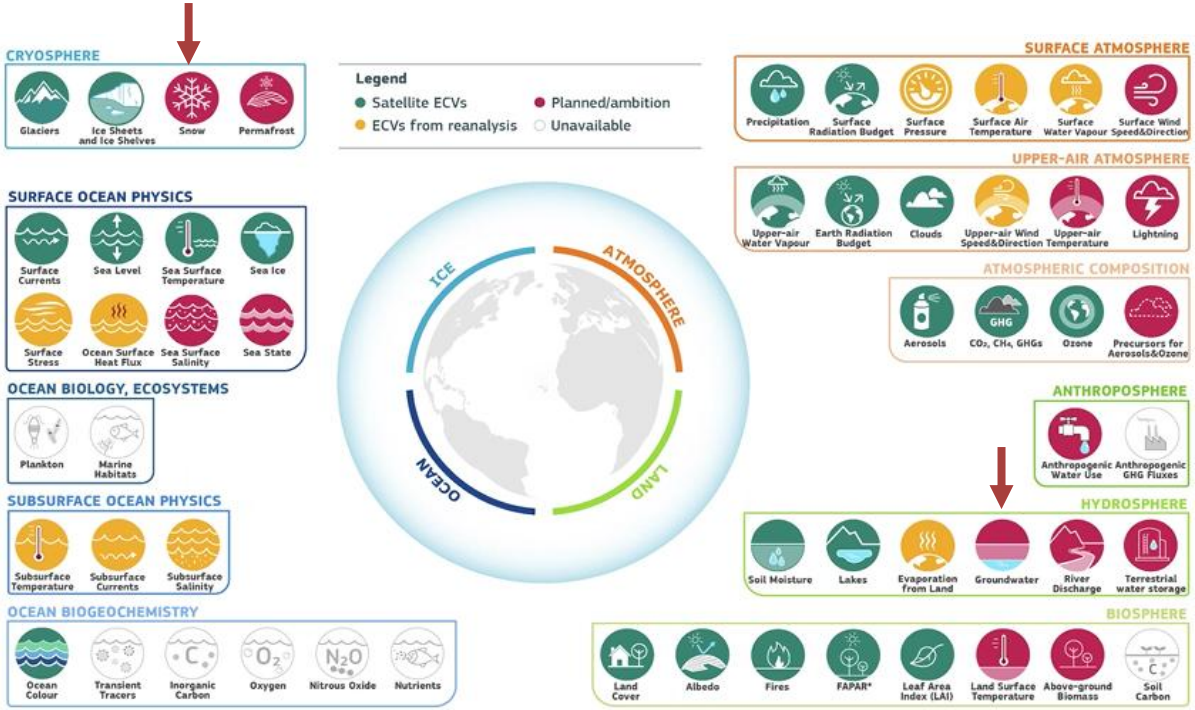
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C3S in a nutshell



Status of Essential Climate Variables (ECV) in C3S and its new service components on snow and groundwater

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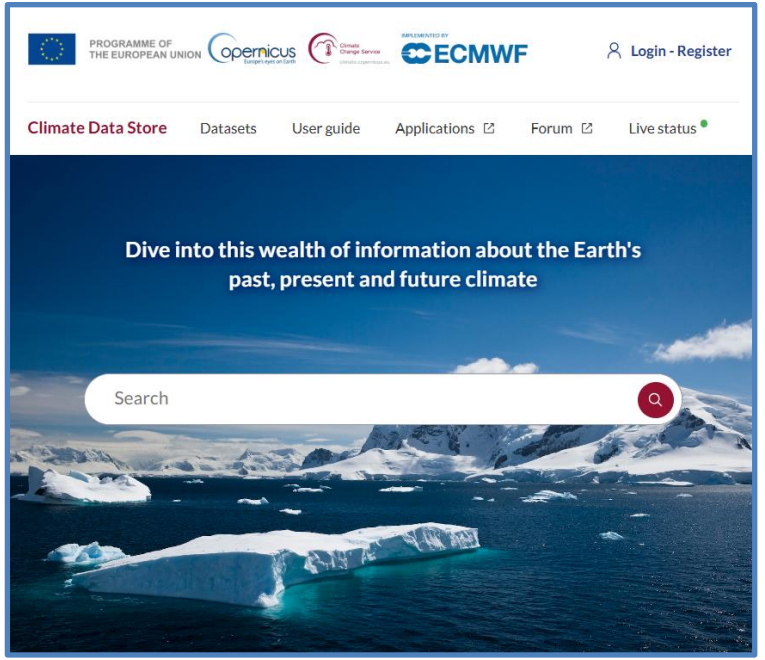
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C3S in a nutshell

Copernicus Climate Change Service (C3S)

enhances the uptake and application of C3S climate data within the Copernicus framework

- ❑ **aims to inform policy development to protect citizens from climate-related hazards such as high-impact weather events**
- ❑ **improve the planning of adaptation practices for key human and societal activities**
- ❑ **promotes the development of new applications and services for the benefit of society**
- ❑ **supports monitoring climate change**



https://cds.climate.copernicus.eu/

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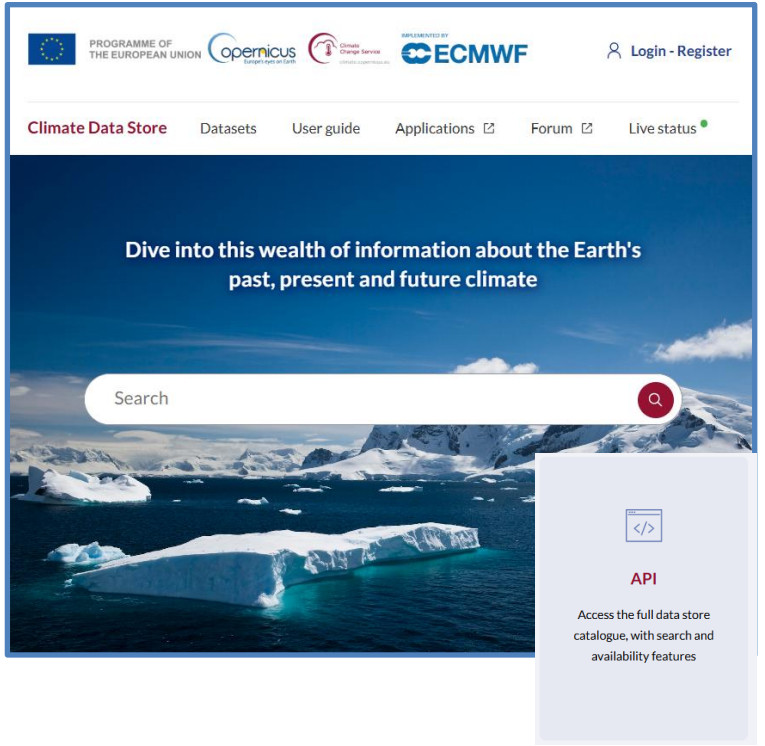
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C3S in a nutshell

Copernicus Climate Change Service (C3S)

provides reliable, open, and free access to a wide variety of Climate Data Records (CDRs)

- ❑ data provision via Copernicus Climate Data Store (CDS) ensures easy access
- ❑ full documentation includes user guides, ATBDs, product validation and user support
- ❑ operational processing and continuous data provision
- ❑ following CF data standard formats, FAIR principles



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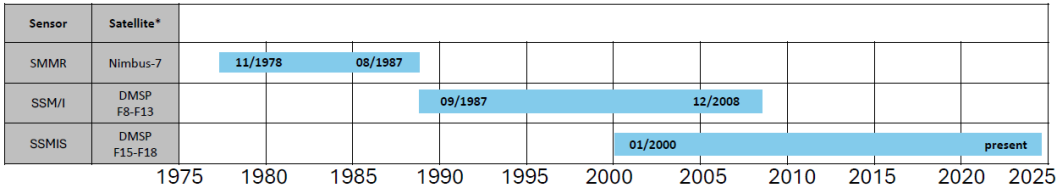
SWE for C3S - cryosphere

C3S cryosphere satellite observation of snow

project timeline: 10/2024-03/2028

SWE retrieval algorithm combines satellite-based passive microwave radiometer data with ground based synoptic snow depth observations using Bayesian data assimilation, incorporating the HUT Snow Emission model.

- ❑ **This includes latest improvements of GlobSnow and Snow CCI SWE production systems (Takala et al. 2011, Luojus et al. 2021, Venäläinen et al. 2023)**
- ❑ **measurements derived from Scanning Multichannel Microwave Radiometer (Nimbus-7 SMMR), Special Sensor Microwave/Imager (DMSP SSM/I) and Special Sensor Microwave Imager/Sounder (DMSP SSMIS) starting in 1979 to present**



*All satellites are in a near-circular, sun-synchronous, polar orbit
Ref: https://nsidc.org/sites/default/files/documents/technical-reference/smmr-ssmi-ssmis-sensors.pdf

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SWE for C3S - cryosphere

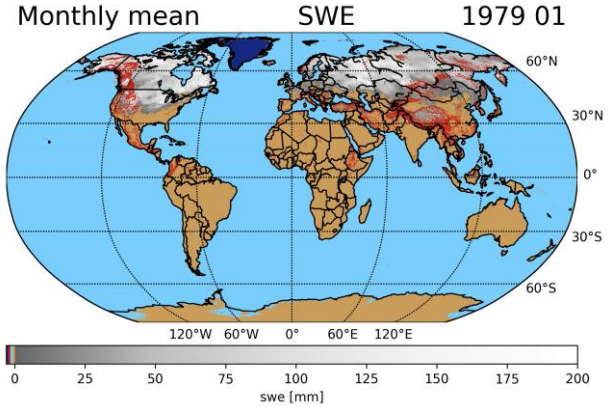
C3S cryosphere satellite observation of snow

project timeline: 10/2024-03/2028

- provision of Snow Water Equivalent (SWE) + pixel level uncertainty estimates

- long-term climate data records of hydrological winter seasons: Oct-May 1979-ongoing
- Quarterly updates
- Approximate latency 3 month

- temporal resolution: daily + monthly
  excluding summer months Jun-Sep
- spatial coverage: Northern hemisphere
  land area only, excluding mountains + glaciers
  0.1° regular lat-lon grid resolution



C3S Snow Water Equivalent (SWE) for Northern hemisphere

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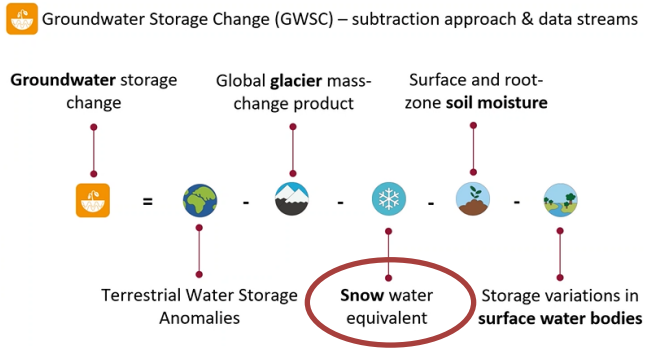
SWE for C3S - hydrology

New ECV on groundwater

GFZ

project timeline: 12/2024-03/2028

- **Terrestrial water storage (TWS) variations can be obtained from Earth's gravity field anomalies (Boergens et al., 2022)**
- **measurements of Gravity Recovery and Climate Experiment (GRACE) satellite mission (2002-2017); GRACE-FO (2018-)**
- **Groundwater Storage Change (GWSC) estimated by subtraction of all remaining water compartments from total terrestrial water storage (TWSA) anomalies (Güntner et al., 2026)**
- **FMI contributes with a global SWE product as combination of satellite (C3S SWE) and model-based SWE (MERRA2 + ERA5-Land)**



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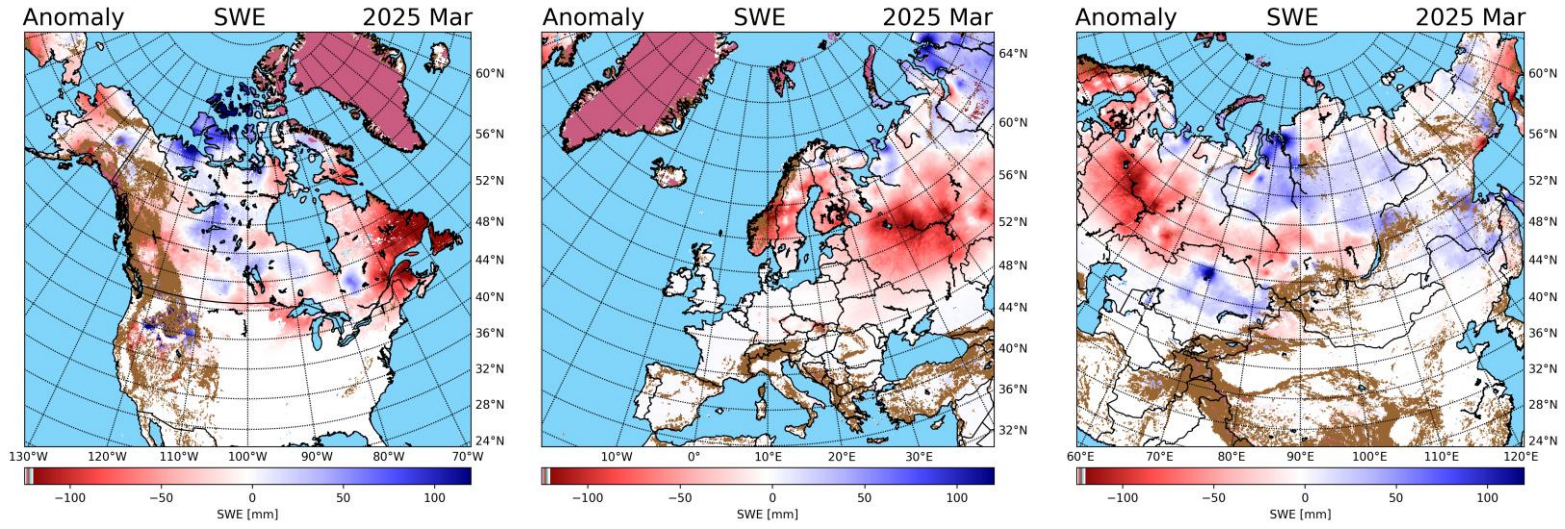
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Longterm observations - some results



Map of Snow Water Equivalent (SWE) anomalies [unit in mm] for March 2025 showing positive [blue] and negative [red] deviations from the 1991–2020 climatological mean

Water bodies, mountains, and glaciers are masked

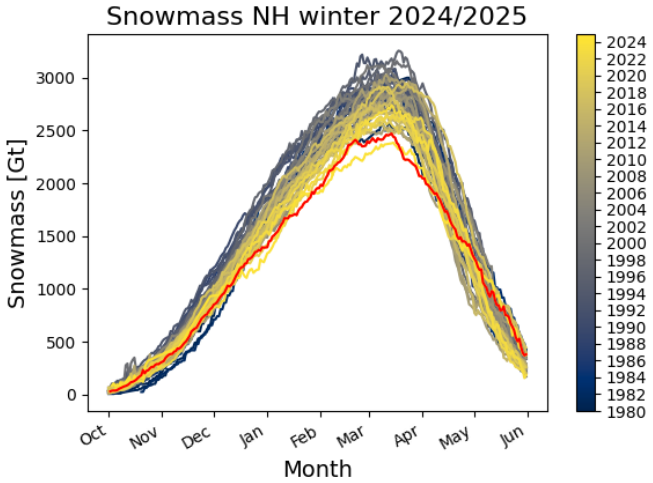
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Longterm observations - some results

Snow mass for Northern hemisphere

- ❑ **derived from satellite-based C3S Snow Water Equivalent (SWE) product v1.0 available since 1979**
- ❑ **Climatological reference period: 1991–2020**



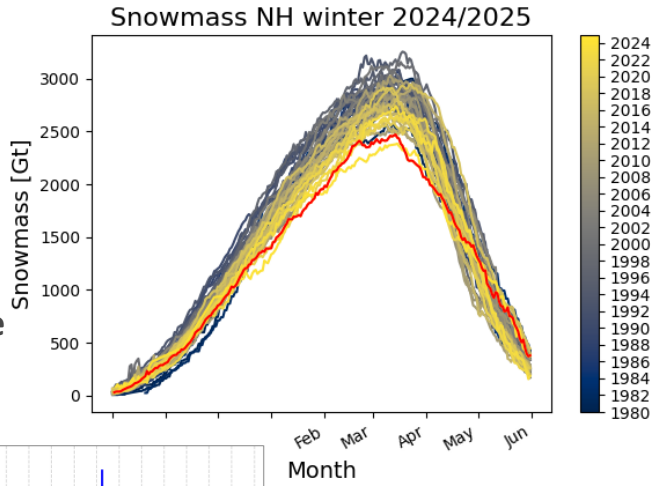
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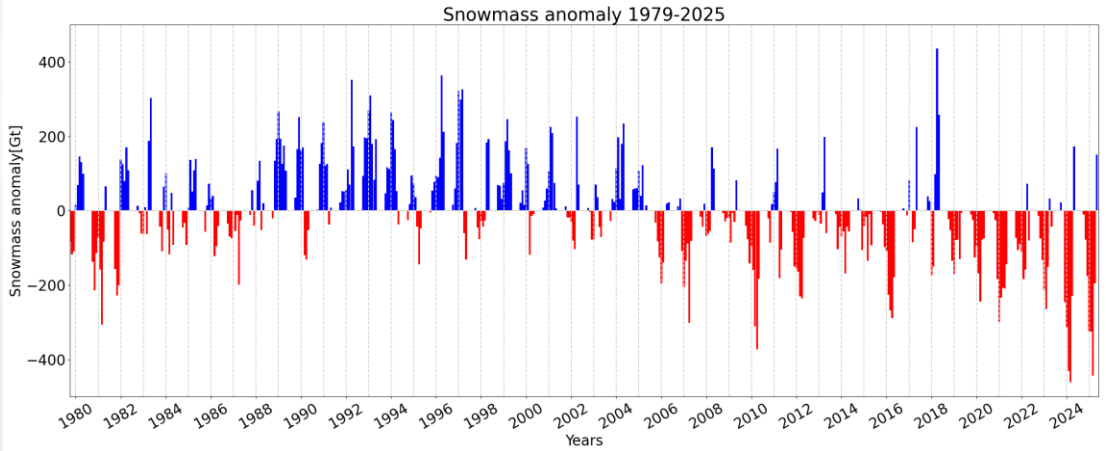
Longterm observations - some results

Snow mass for Northern hemisphere

- derived from satellite-based C3S Snow Water Equivalent (SWE) product v1.0 available since 1979
- Climatological reference period: 1991–2020

- Stronger winters with positive anomalies were more prone in earlier decades of 1979-2005



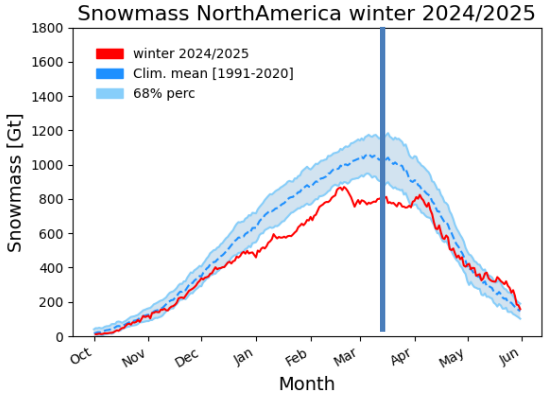


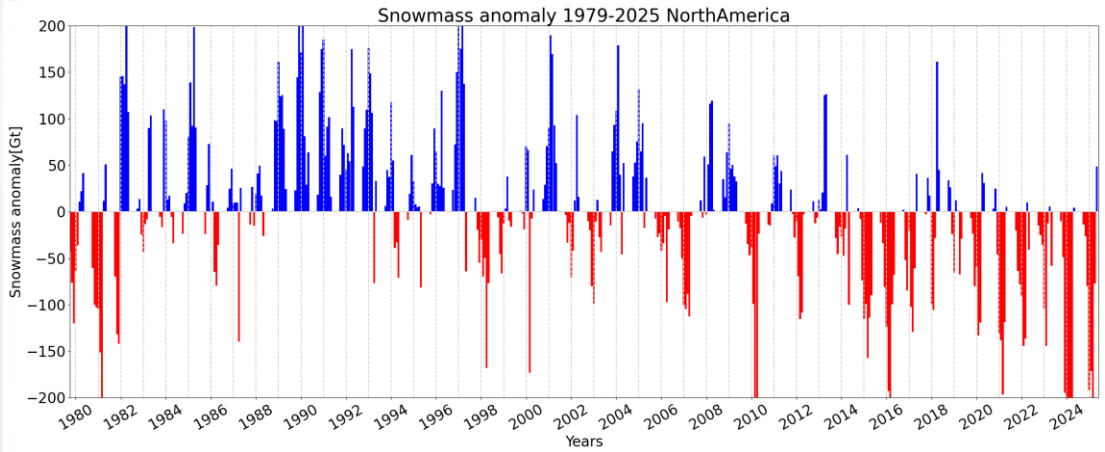
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Longterm observations - some results

Snow mass for North America (WMO region 4 domain)

- ❑ **Winter seasons with less snow than clim. mean are becoming more frequent since ~2005**
- ❑ **Snow mass maximum between March/April (~1050 Gt)**



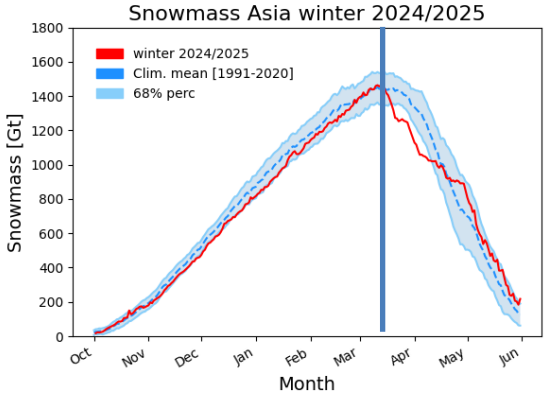


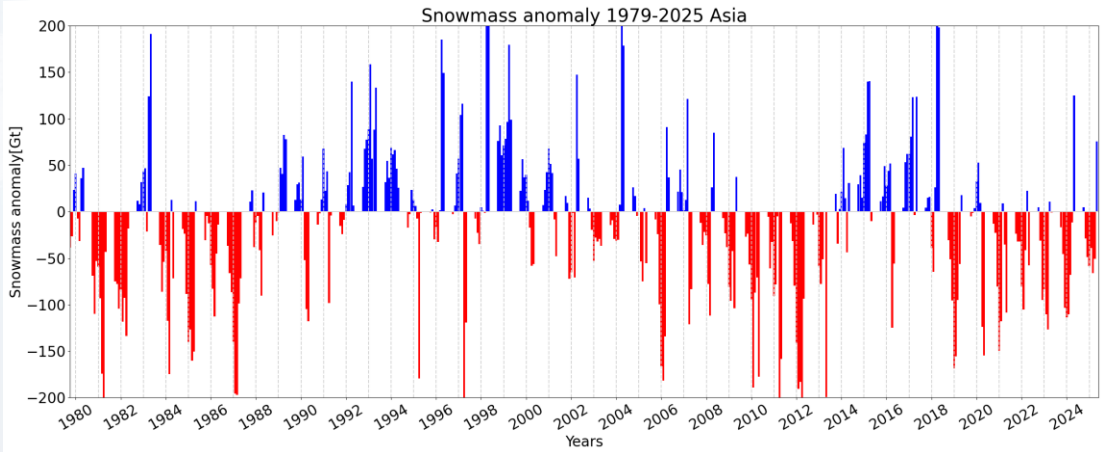
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Longterm observations - some results

Snow mass for Asia (WMO region 2 domain)

- Snow mass maximum between March/April
- With ~1500 Gt in peak winter season Asia contributes the biggest amount of snow to the global distribution



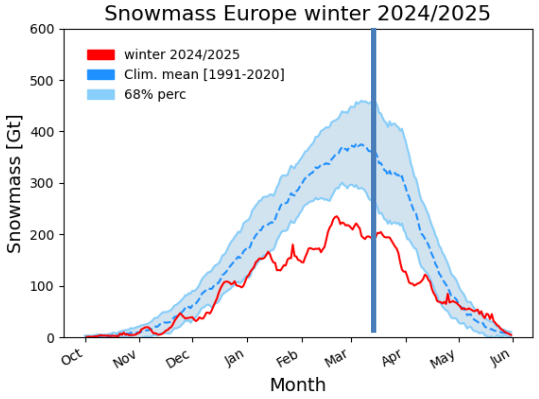


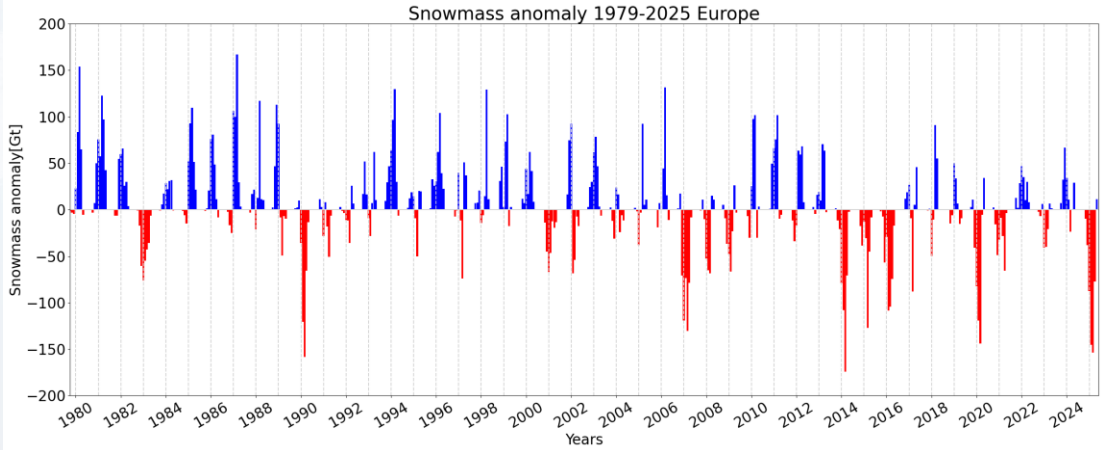
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Longterm observations - some results

Snow mass for Europe (WMO region 6 domain)

- European snow mass in March 2025 was about 153.63 Gt below the 1991–2020 clim. Average
- March 2025 had the third lowest observed snow mass in Europe since 1979
- The number of armer winter with negative anomalies increasing since 2005 even though trend of decreasing snow mass for Europe is not as significant as observed for the full Northern hemisphere





Average atmospheric circulation pattern for winter 2024/2025 in Europe with anticyclonic high-pressure systems, could have led to transport of warmer temperatures towards the Nordics

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Summary

C3S offers new services for the cryosphere and hydrology:

- ❑ **New ECV on satellite-based observations of Snow Water Equivalent (SWE) [data record 1979-ongoing]**
- ❑ **C3S SWE is additionally part of new production scheme for global ECV on groundwater [data record 2002-ongoing]**

- ❑ **continuous data provision (quarterly updates) of validated and quality controlled ECVs**

Over 40 years satellite observations on SWE and snow mass help to assess changing climate on various scales

Copernicus Climate Data Store (CDS) allows easy data access

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Thank you very much!
Questions?

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