sea ice cci

greenland ice sheet cci

antarctic ice sheet cci

glaciers cci

snow cci

permafrost cci

# CRYOSPHERE ECVS

**Louise Sandberg Sørensen**, Annett Bartsch, Thomas Lavergne, Frank Paul, Thomas Nagler and Andrew Shepherd

CLIMATE CHANGE INITIATIVE MID-TERM REVIEW

# SCIENCE QUESTIONS

Snow:

- Which regions are critically affected by changes in snow extent, onset and depletion dates?
- How much water is stored in the snowpack and how does it respond to projected climate changes?
- To what extent do variations in snow extent and mass influence the Earth's energy and water budgets?

Sea ice:

- How to handle sea ice volume/mass time series for Arctic and Antarctic starting in the 90s, requiring gap -filling?
- What is the impact of recent extremes in Antarctic sea ice extent on thickness and volume?
- How to to reduce uncertainties in sea ice mass balance estimates?

Permafrost:

- How does permafrost change across the globe, in lowlands and mountain regions (temperature, thaw depth, extent, rock glacier kinematics)
- How does the permafrost state relate to abrupt thaw and carbon release (and tipping)?

# SCIENCE QUESTIONS

Glaciers:

- How do glaciers change (area, elevation, velocity) in key regions globally?
- What are the sensor limits and possible synergies to detect glacier changes?
- Why do glaciers in some regions of the world advance?

Ice sheets:

- Tracking the ice sheet contribution to global sea level rise
- How to improving predictions of future sea level rise?
- What are the impacts of ice melting on ocean circulation?
- Investigation of  Tipping points and the potential for ice sheet collapse.

# OBSERVATIONAL CHALLENGES

Snow:

- Low solar illumination conditions for retrieving snow extent (shaded regions, close to regions with polar night)
- Discrimination of snow and clouds with optical satellite data
- Retrieval of snow mass (snow water equivalent) at high spatial resolution, of particular relevance for mountain areas and complex terrain

Sea ice:

- Melt onset introduces uncertainties in sea ice products
- The pole hole data gap (altimeters) complicates the computation of pan-Arctic sea ice mass and volume.

Permafrost:

- Cloud cover considerably reduces the availability of land surface temperature observations
- Global landcover datasets are inadequate for soil parameterization of the permafrost model
- To date available LST data are too coarse to represent the typical landscape heterogeneity
- SWE is too coarse to be used for the permafrost modelling. At least 1km to meet the user requirements.
- Sampling intervals of SAR data critical for rock glacier kinematics

# OBSERVATIONAL CHALLENGES

Glaciers:

- Cloud cover considerably reduces the number of useful optical images, SAR has issues in steep topography
- The DEMs used for orthorectification are too coarse and old for proper geocoding in steep high-mountain terrain
- There is yet no automated approach (AI/DL) replacing manual editing of outlines from debris-covered glaciers
- The northern parts of Greenland & Ellesmere are not covered by Landsat / Sentinel-2 => no ice shelf monitoring
- There is very little money availble to (operationally) convert the wealth of satellite data into useful products

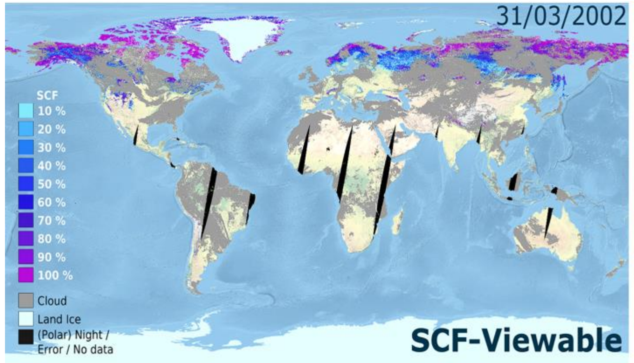
Ice sheets

- Bridging the gap between CryoSat-2 and CRISTAL
- Reconciling satellite estimates of ice sheet mass balance at regional scale
- Partitioning ice sheet surface and dynamical mass balance
- Tracking tipping points for early warning systems

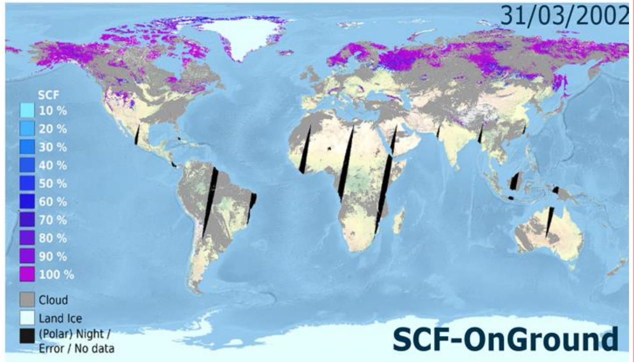
# Snow CCI – Thomas Nagler (ENVEO)

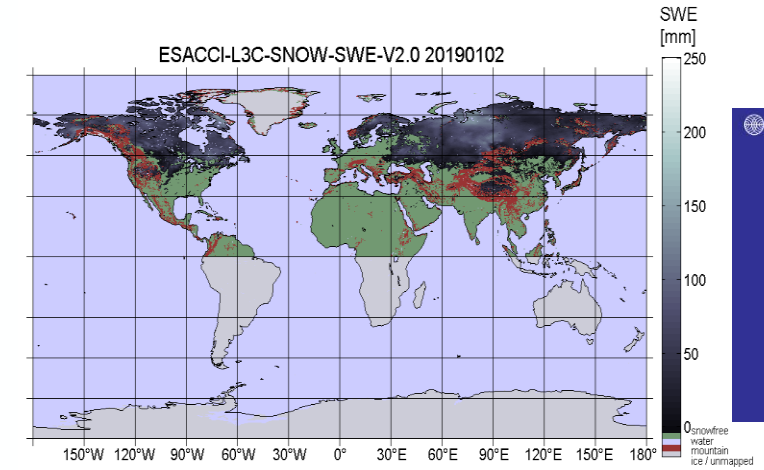
Seasonal snow is the largest individual component of the cryosphere, covering an average winter maximum area of about 46 million square kilometers. It exhibits significant temporal and spatial variability.

Viewable Snow

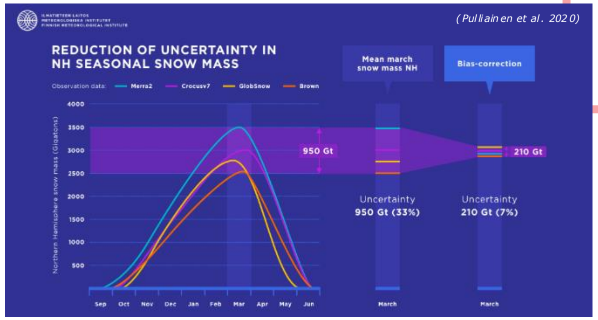



Snow on Ground (canopy corrected)




Snow Water Equivalent




- CCI Snow provides a homogenized time series of more than 40 years of two key parameters of the seasonal snow
  - Snow Extent – daily, global, 1 to 5 km
  - Snow water equivalent – daily, Northern Hemisphere, (without mountains), 10 km
- Provides essential information on short and long term variations in snow patterns and mass distribution, impacting the availability of water resources
- Use of CCI Snow products in different applications, e.g. estimation of trends, runoff estimations, land process models

enveo ECCC eurac research SYKE FMI NR cnrs IGE SMHI The University of Edinburgh u^b Universität Bern GAMMA

# Snow CCI – Thomas Nagler (ENVEO)

Next steps include development of algorithms & improvement of products

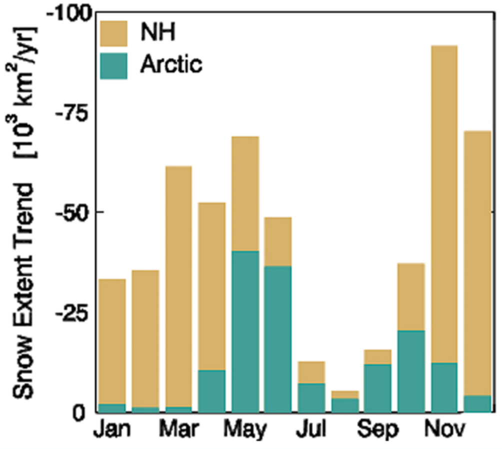
(i) homogenisation of snow products from different sensors

(ii) advancing snow retrieval algorithms and improve resolution for mountains and complex terrain

(iii) improvement of gap-filling of snow extent products

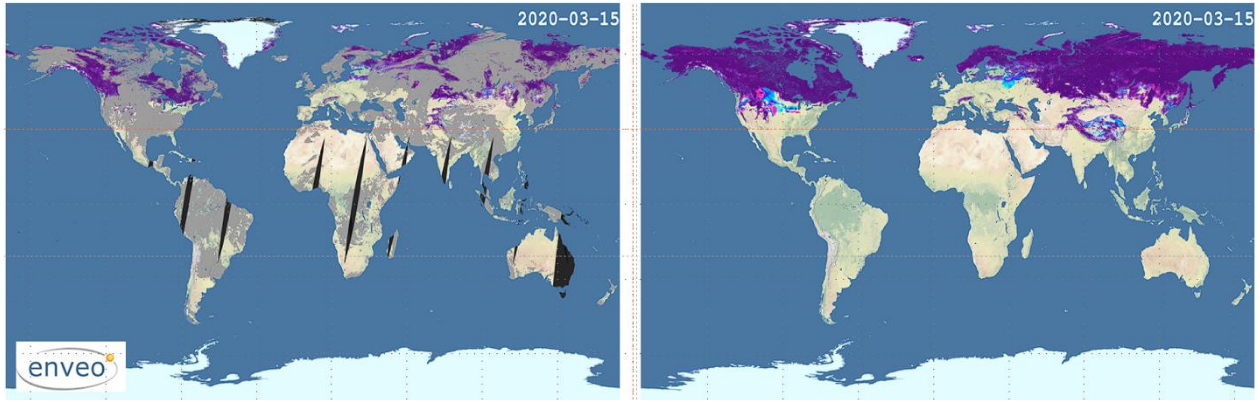
(iv) improve aggregation methods for estimating monthly products from daily observations

Snow extent trends over 1981–2017 from multi-products




*(Derksen & Mydruk, 2023)*

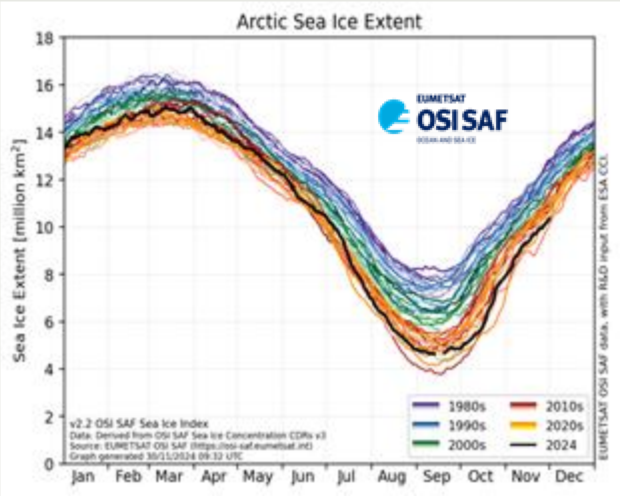
Cloud-gap-filled snow cover extent



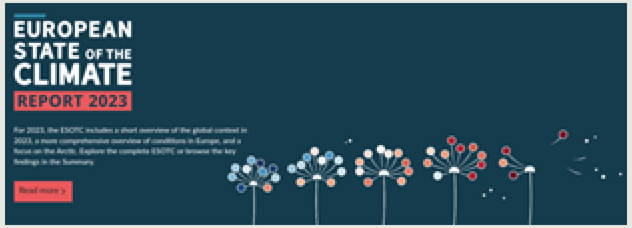

New products and new satellites

- CDR of gap filled daily global snow extent product
- High resolution snow extent and wet snow products for mountains
- CDR of monthly averaged snow products
- New sensors: CIMR, Sentinel-3C/D, Sentinel-2C/D, CHIME, Sentinel-1C/D

# Sea Ice CCI – Thomas Lavergne (METNO), Robert Ricker (NORCE)



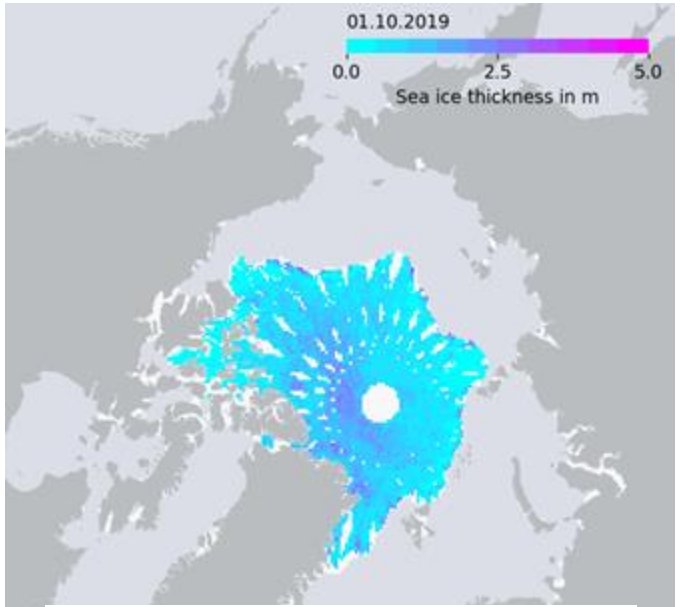

CCI R&D supports **operational monitoring** by OSI SAF, Copernicus Marine and Climate Change Services



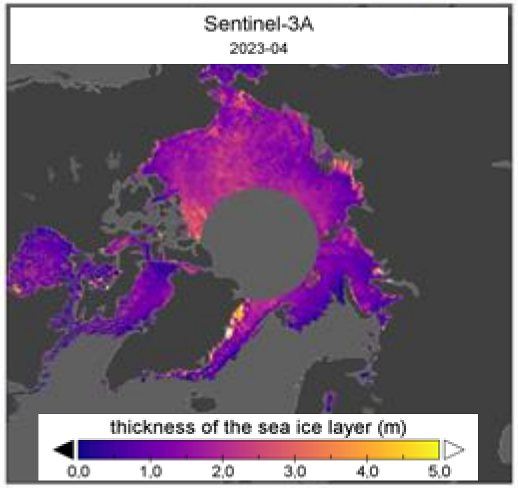

EUMETSAT OSI SAF · Copernicus Marine Service · Climate Change Service

Innovative R&D to better exploit **ESA/Copernicus radar altimetry missions** for sea-ice thickness monitoring

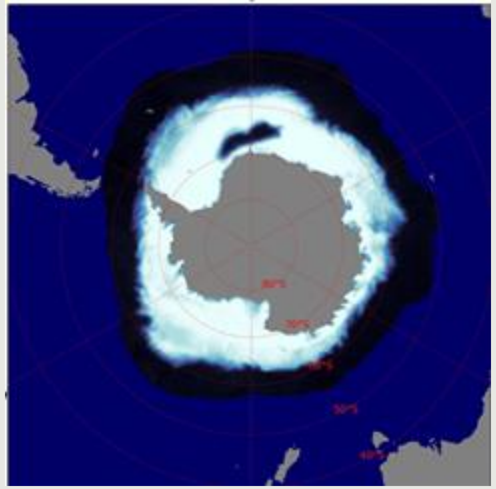
- exploit Sentinel-3A and 3B (**right**)
- improve sea-ice thickness mapping using sea-ice motion products (**below**)




Drift-Aware daily sea-ice thickness for ESA CryoSat-2




Explore **precursor** satellites



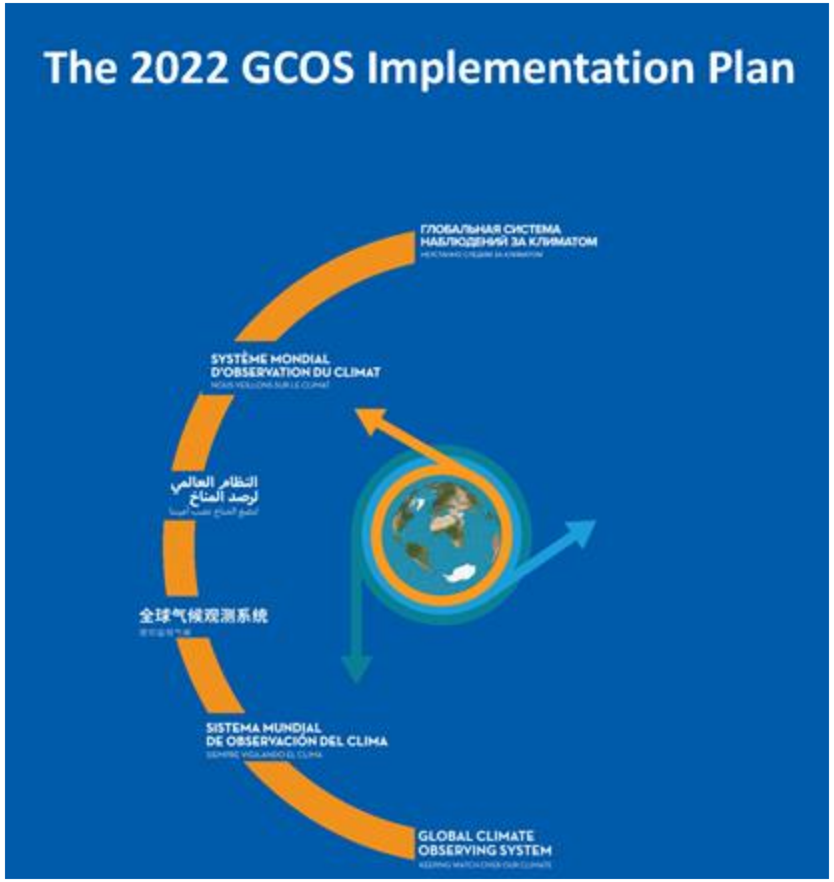
Sea-ice map with ESMR Nimbus-5 (Oct 1974)

# Sea Ice CCI – Thomas Lavergne (METNO), Robert Ricker (NORCE)

## Next steps and future perspectives

**Next Steps for sea-ice concentration and thickness**

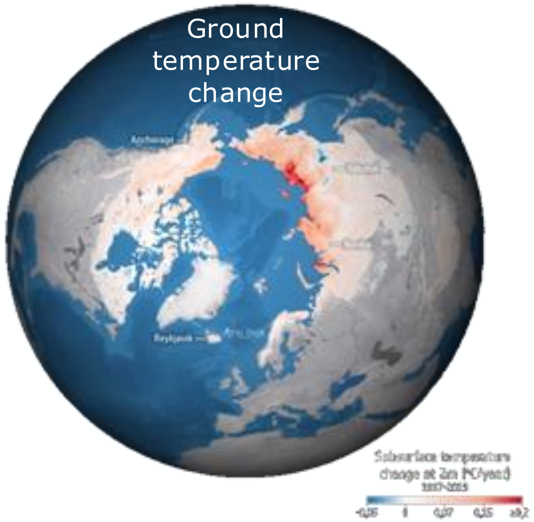
- Improve melt/freeze detection
- Interpolation of *pole hole* data gap (altimetry)
- Extend *Drift-Aware sea ice thickness* to the southern hemisphere
- Liaise with CMIP AR7 community

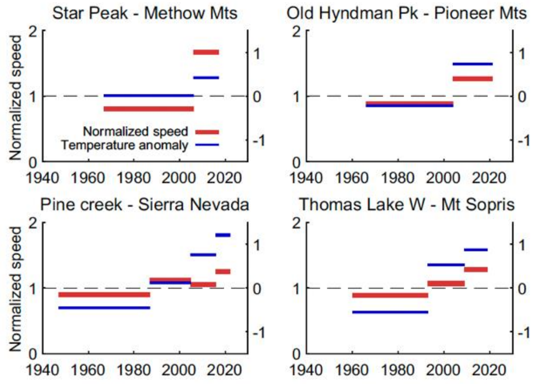



CCI has focused on sea-ice *concentration* and *thickness*. There are **five more ECV quantities** to cover in the GCOS IP. Let's get started!

**CRISTAL** and **CIMR** will both critically contribute to the monitoring of polar sea ice. All the sea ice variables of GCOS will be covered. We must plan for synergies.

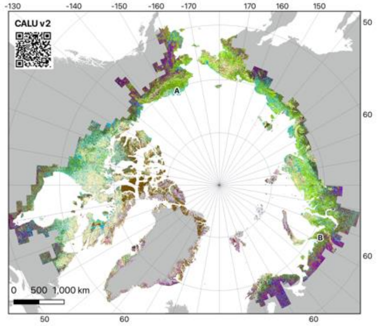
# Permafrost CCI – Annett Bartsch (b.geos)



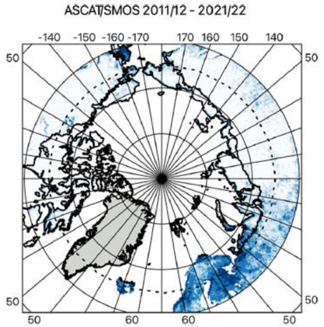




Increasing rock glacier velocities

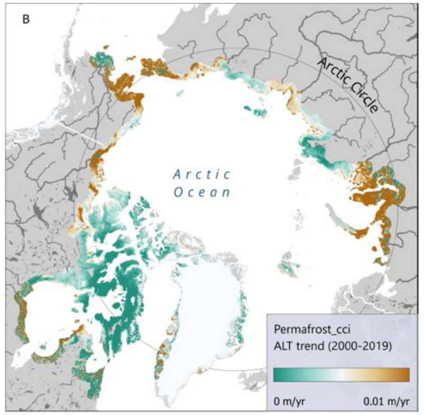
- Approach: Combination of satellite observations and modelling
- We produce long-term records of permafrost ground temperature, active layer thickness, extent and rock glacier kinematics (new ECV parameter)
  - Guidelines for inventorying the kinematic attribute of rock glaciers have been developed
- In situ records essential for cal/val  harmonized and published
- Novel landcover based on Sentinel-1/2 developed to support model parameterization
- Complementing datasets: freeze/thaw of soils and rain on snow: roadmaps developed for climate data record retrievals
- Applications beyond climate modelling include e.g. infrastructure risk assessments




Parameterization: Novel Arctic specific landcover based in Sentinel-1/2




Complementary:
Rain-on-snow events (impacting thermal properties)




Use case:
Near coastal active layer change for infrastructure risk assessment

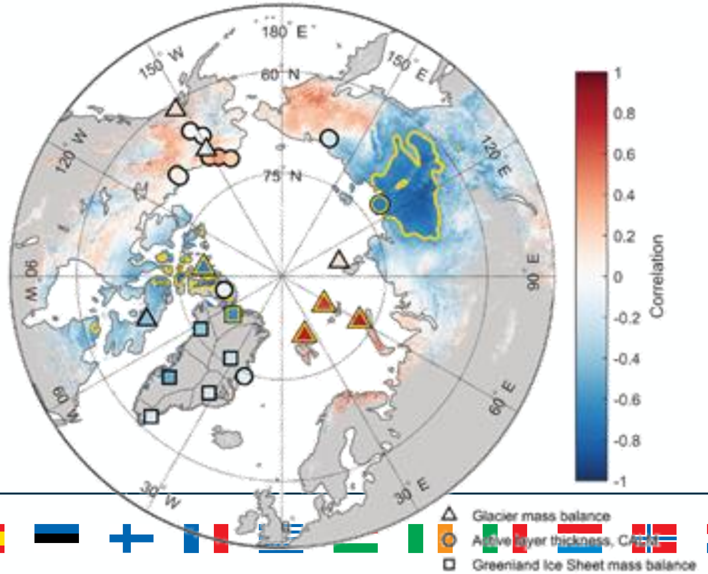
GAMMA REMOTE SENSING
b·geos
UiO
UNI FR
West University of Timisoara
NORCE

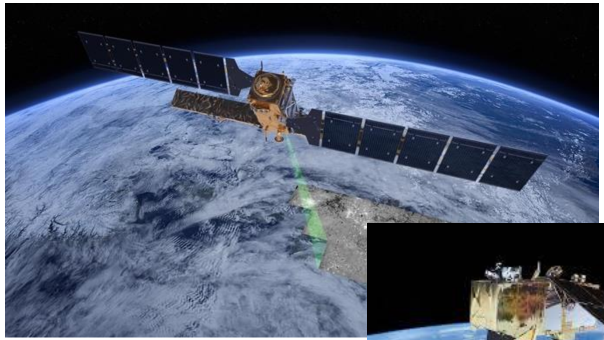
# Permafrost CCI – Annett Bartsch (b.geos)

## Next steps and future perspectives

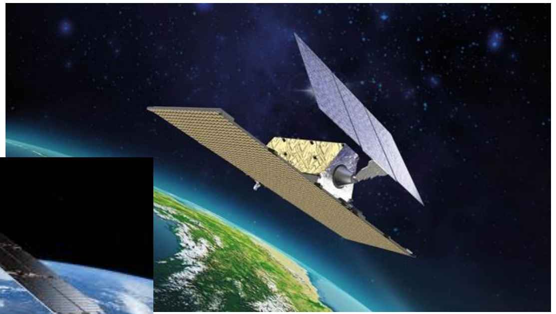
- Model improvements and extensions:
  - Ingestion of CCI land surface temperature
  - Potential extension to Antarctica
  - Quantification of vegetation effects
- To be considered: Abrupt thaw feature monitoring in the context of clustered tipping
- New science – use cases, excess ice melt

Correlation of active layer thickness change with Greenland glacier mass balance



Sentinel-1C



ROSE-L

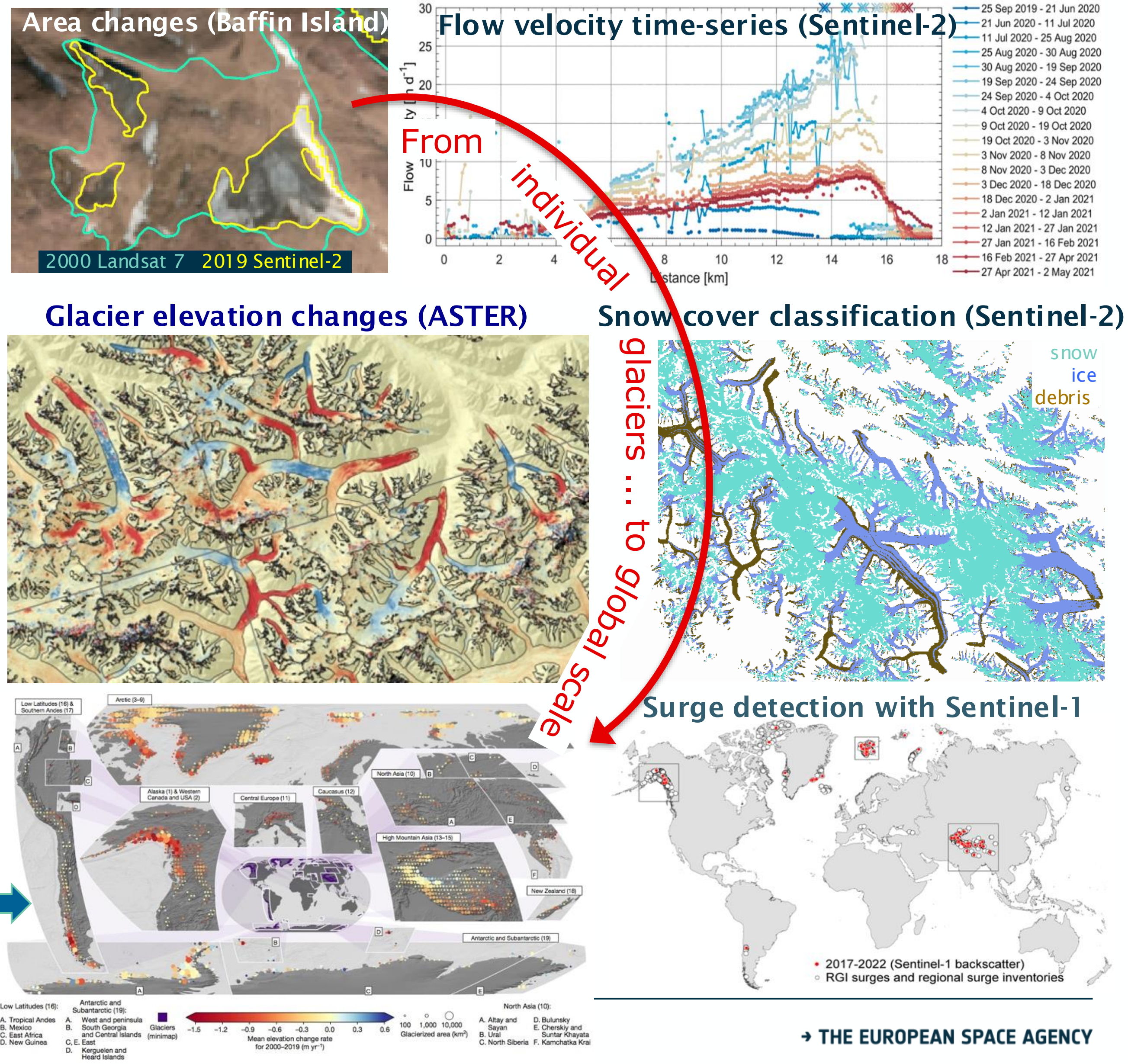
Sentinel-2C

## Future missions

- Use of data from new sensors for thaw subsidence and landcover
- Steps towards a standardised and consistent approach for rock glacier velocity generation using satellite radar interferometry are currently being taken using Sentinel-1 data. However, a higher spatial and temporal resolution should be considered for future missions.

# Glaciers CCI – Frank Paul (University of Zurich)

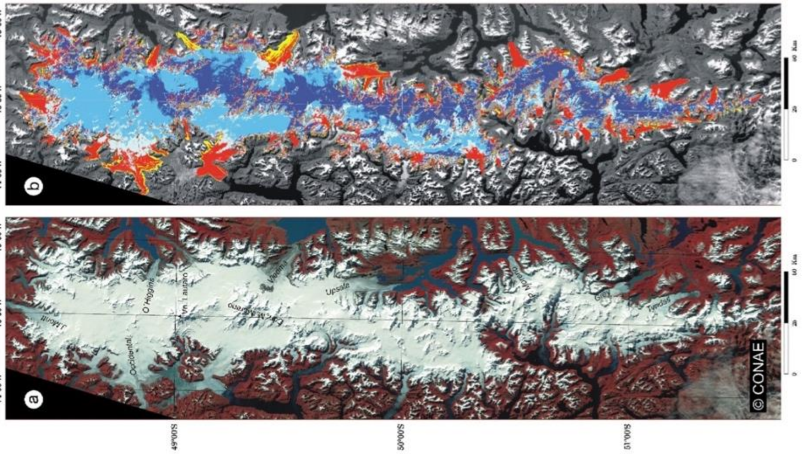
- We develop **methods** for optical, radar and altimeter sensors to derive glacier area, elevation change, velocity, snow cover and surge detection **products**
- The methods & products contribute to **global datasets** providing key information on glacier extent (RGI) and mass change **for IPCC AR/SR** & the user community
- Our scientific focus was on the analysis of unstable glaciers in **High Mountain Asia** and the **Arctic**.
- **20+ articles** were published from **2021 to 2024**, incl. **Science**, **Nature**, Nature Comm., Cryosphere, JoG, ...

# Glaciers CCI – Frank Paul (Univ. of Zurich)

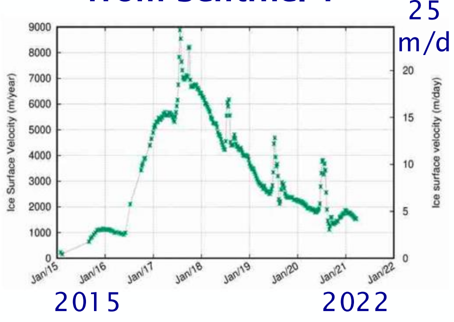
- In a possible **Glaciers_cci+ Phase 3** we will focus on Svalbard & Patagonia and analyse if we can derive snow thickness maps from snow extents (Sentinel-2, Landsat) combined with elevation data (ICESat-2)
- We further intend exploiting new (SAOCOM, ICEYE, NISAR) and heritage SAR missions (ERS1/2, JERS-1, ENVISAT, Radarsat-1/2) for surge detection, flow velocities and specific glaciological applications

**Snow zonation map (S. Patagonian Icefield)**



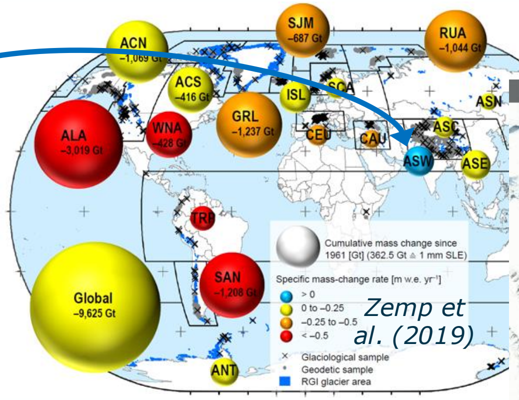

*De Angelis et al. (2007)*

**Flow velocity time series for Negribreen from Sentinel-1**



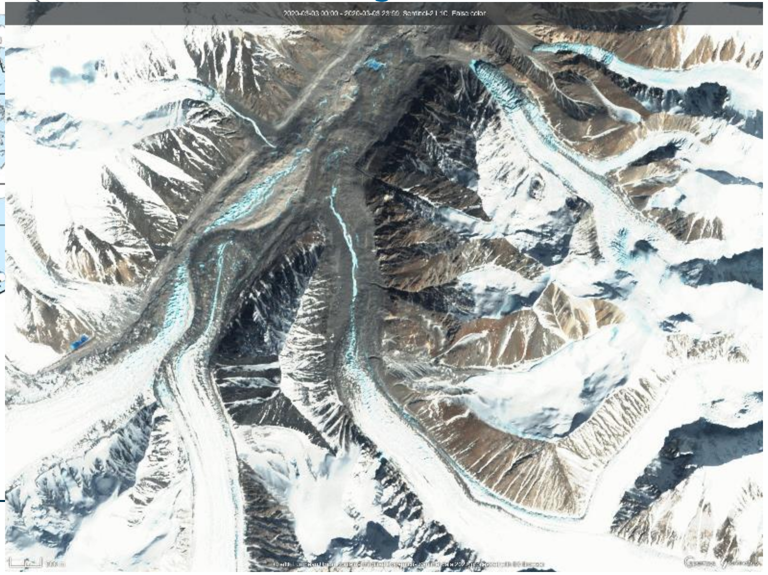

*Strozzi et al. (2023)*

- The **new X-ECV project** will investigate why in a small part of the world glaciers gain mass & grow (blue ball)
- For this purpose we will combine various products from EO sensors (snow cover, DEMs) with climate data (re-analysis, climatologies) to force a mass balance model
- Main question: Can climate data explain the blue ball?
- We also hope to find why some glaciers in the region are surging whereas most others are not.

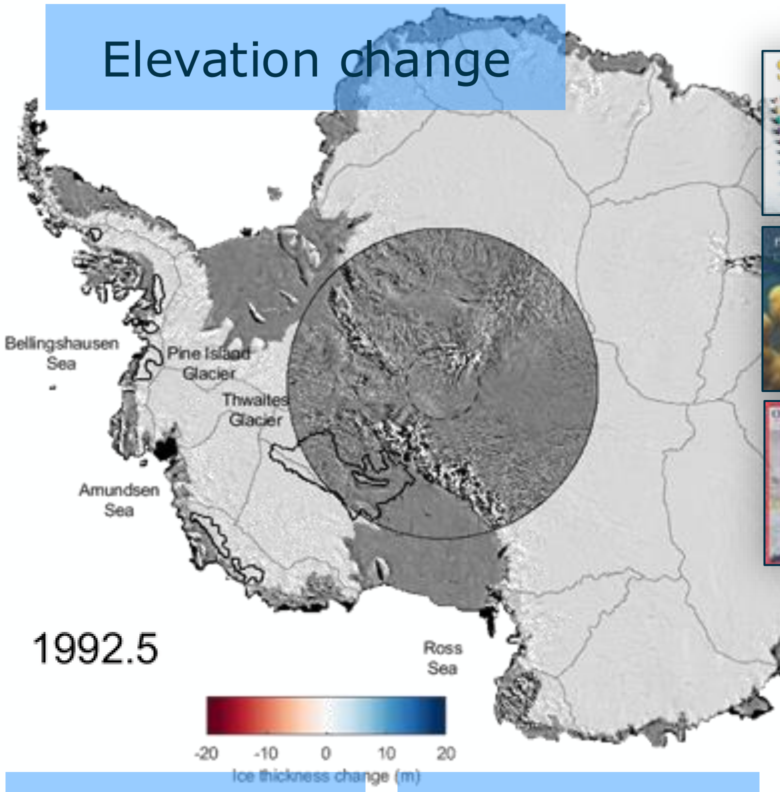


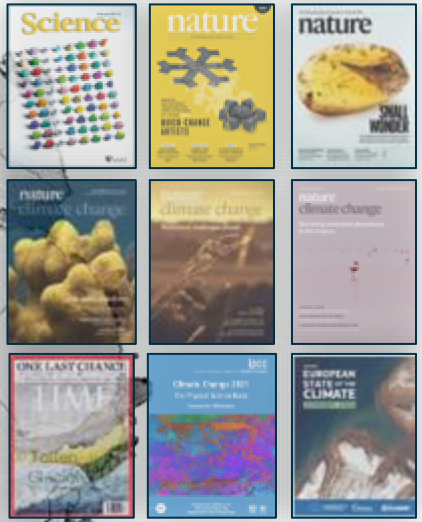

**Cumulative glacier mass balance (1961-2016) in Gt (ball size) and specific value in mm w.e. (colour)**

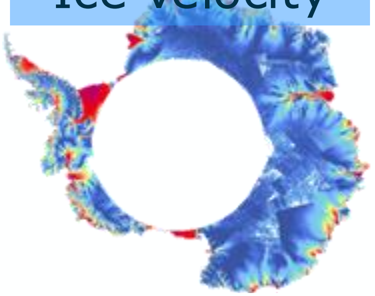
**Four different glacier surges at the same time in the same region (8-2020 to 5-2022)**



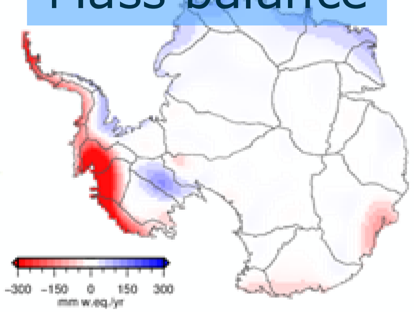
# Antarctic Ice Sheet CCI – Andy Shepherd (CPOM)








- Satellites are the only practical method of tracking changes in Earth's polar regions
- We produce long-term records of Antarctic ice sheet elevation, velocity, grounding line, and mass change
- Primarily from past (E1, E2, EV) and current (CS2, S1, S2, S3) ESA missions
- Over 10,000 uses of data from our portals
- Central to global assessments of sea level rise, IPCC assessment reports, and state of the climate reports
- Critical boundary conditions for global climate models
- Underpin many high impact scientific discoveries

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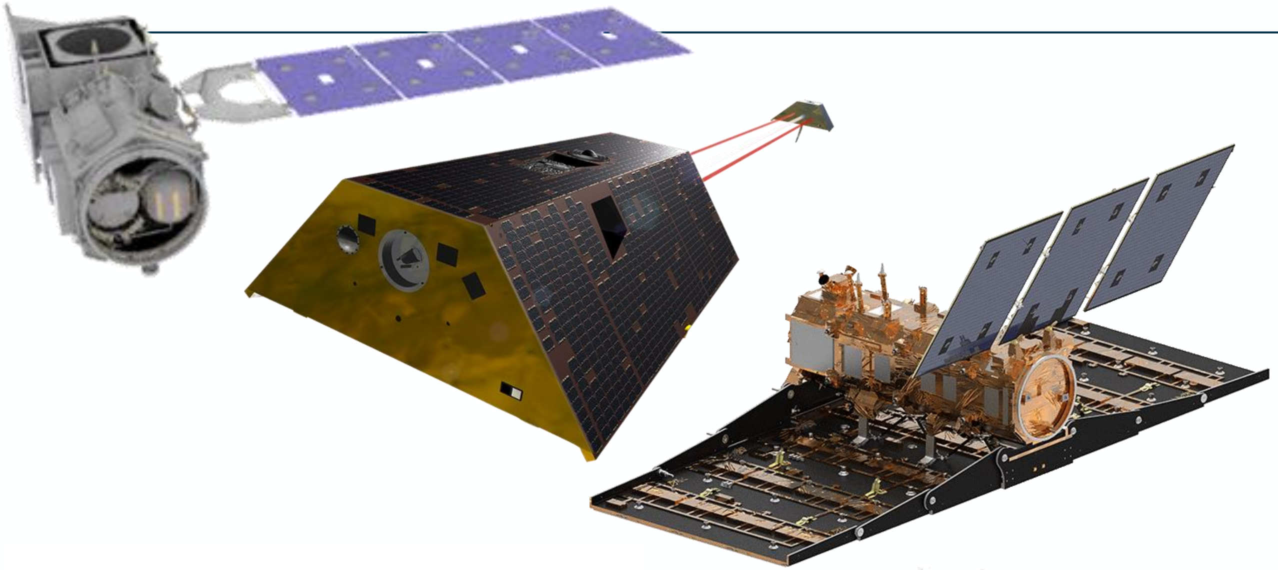
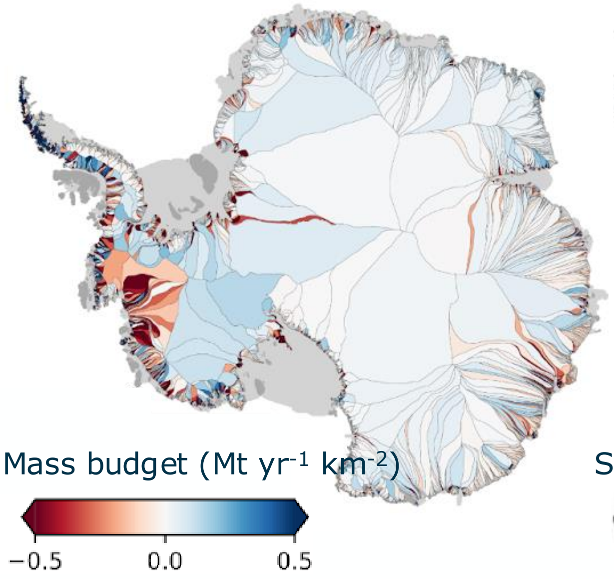
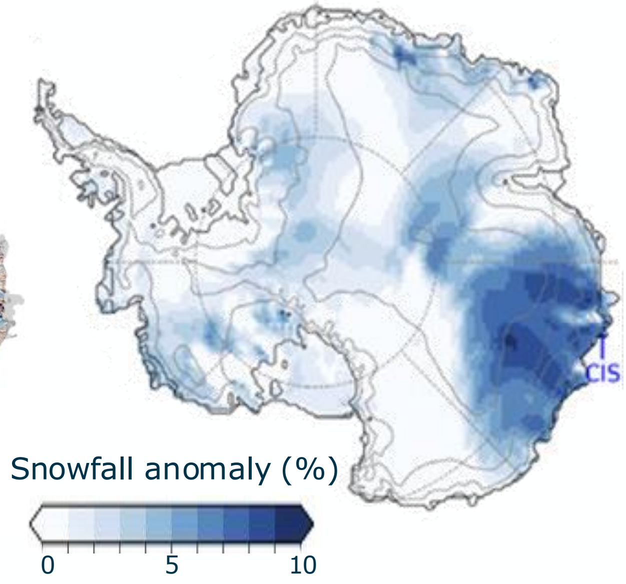
# Antarctic Ice Sheet CCI – Andy Shepherd (CPOM)



- Next steps are (1) improve methods, (2) expand products, (3) exploit new missions, and (4) tackle science challenges
- Method improvements are altimeter backscatter correction, InSAR augmented ice velocity, gravimetry ellipsoidal correction, and AI/ML grounding lines
- New products are ice velocity change, grounding line migration, and partitioned mass balance
- New missions are ICESat-2, GRACE-FO, and SAOCOM
- New science is fine resolution mass balance and partitioning meteorological and dynamic mass balance

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# CCI Greenland Ice Sheet – Louise Sandberg Sørensen (DTU)

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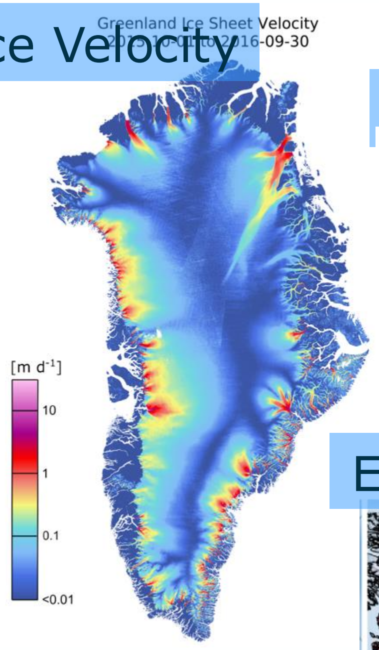
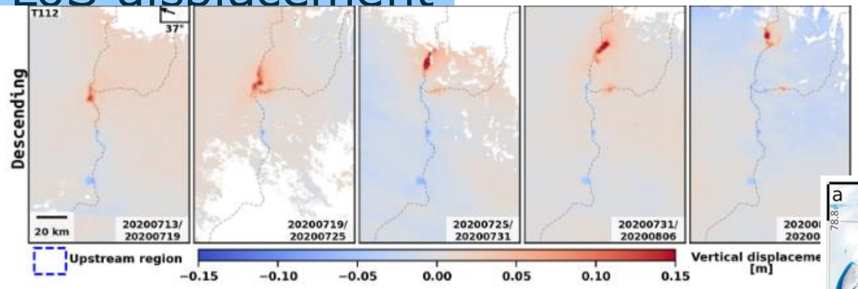
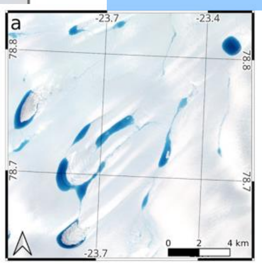
Ice Velocity



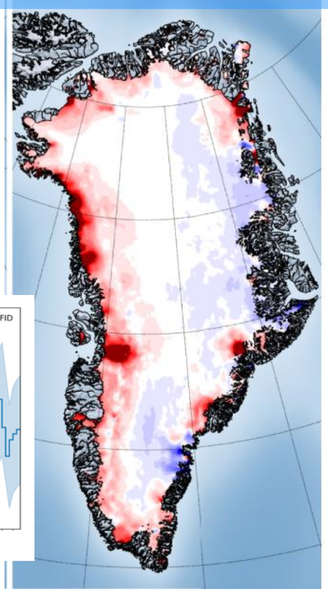

LoS displacement



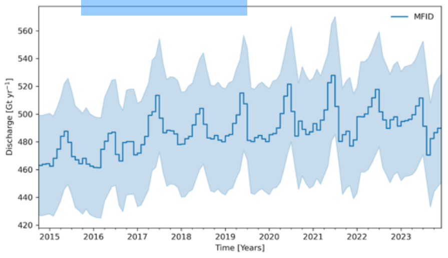

Lakes

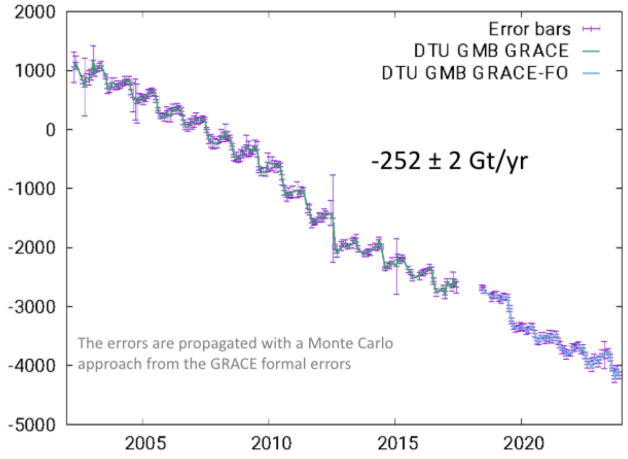



Elevation change



MFID

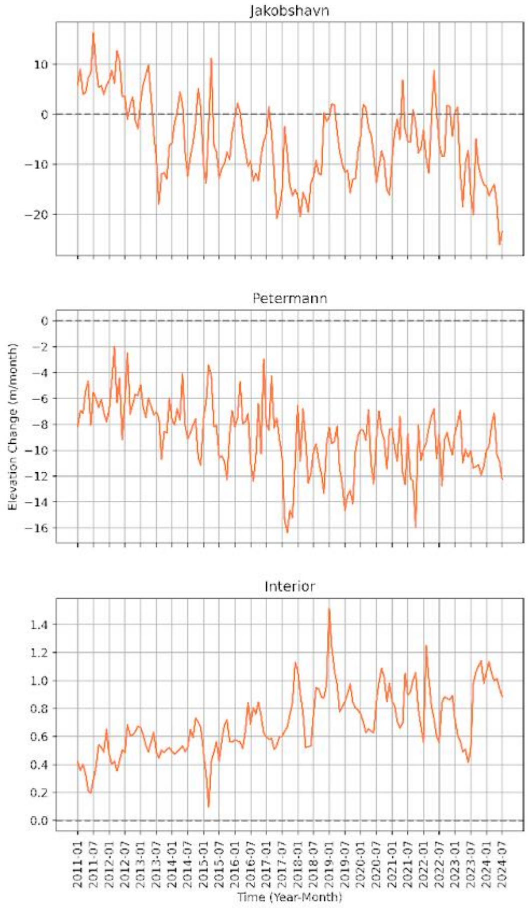



Mass balance

- We have generated long-term data records of Greenland ice sheet elevation trends, velocity, mass balance and ice discharge
- New products : high resolution elevation changes, Supraglacial lakes, Line of Sight displacements
- Important for seal level rise, and freshening.
- IPCC assessment reports, and state of the climate reports
- Ported R&D to C3S

# CCI Greenland Ice Sheet – Louise Sandberg Sørensen (DTU)





- Next steps :
- Update of algorithm: MFID algorithm to incorporate high-resolution elevation change product.
- Update of algorithm: Outlier filtering in the high-res elevation change processor.
- Improve the monthly uncertainties on GRACE estimates
- Calving front position dataset was discontinued several years back. Update this.
- New missions are ICESat-2, GRACE-FO, and SAOCOM
- New science on e.g. extreme precipitation events.
- Comparisons to regional climate / surface mass balance models

# LINKS & INTERCONNECTIONS

The Cryosphere ECVs are involved in several newly started cross-ECV and Tipping Point projects:

ARCFRESH on the Arctic Ocean freshwater budget (snow, sea ice, Greenland ice sheet)

Karakoram Anomaly (glaciers, snow)

X-Fires

Copernicus Climate Change Service

Several parameters included in C3S from the cryosphere ECVs

Horizon Project Icelink

C3S Cryosphere is extended by Snow Service building on Current Snow CCI products

Link to international initiatives and organisation, including “SnowPEx –Satellite Snow Product Intercomparison and Evaluation Exercise”, WMO Global Cryosphere Watch, ECMWF ERA5, SnowMIPs, CEOS LPVE,

# LINKS & INTERCONNECTIONS

Ice sheets:

Ice melting and earths energy imbalance

Ocean and atmospheric forcing of ice sheet instability

Impacts of ice loss on sea level and ocean circulation

# PRIORITIES FOR CLIMATE SPACE

Cryosphere ECVs:

- Improving algorithms and processing lines for advancing current products and development of new products using data from current and new missions (Copernicus Expansion missions, Earth Explorers, Scouts, etc.)
- Exploit Machine Learning/AI, e.g., for gap-filling techniques
- Integration of new satellite sensors
- Enhancing the visibility of CCI and underlining its relevance (e.g., for IPCC and other climate assessments)
- Contributing EO data and related R&D to answer key science questions
- Include modellers who use EO data in research consortia to benefit from related publications.
- Ensure continues uptake of data by modelers
- Identifying climate pathways
- Early warning systems