

Greenland Surface Runoff Extent; *Mapped From Daily MODIS Imagery 2000 To 2021*

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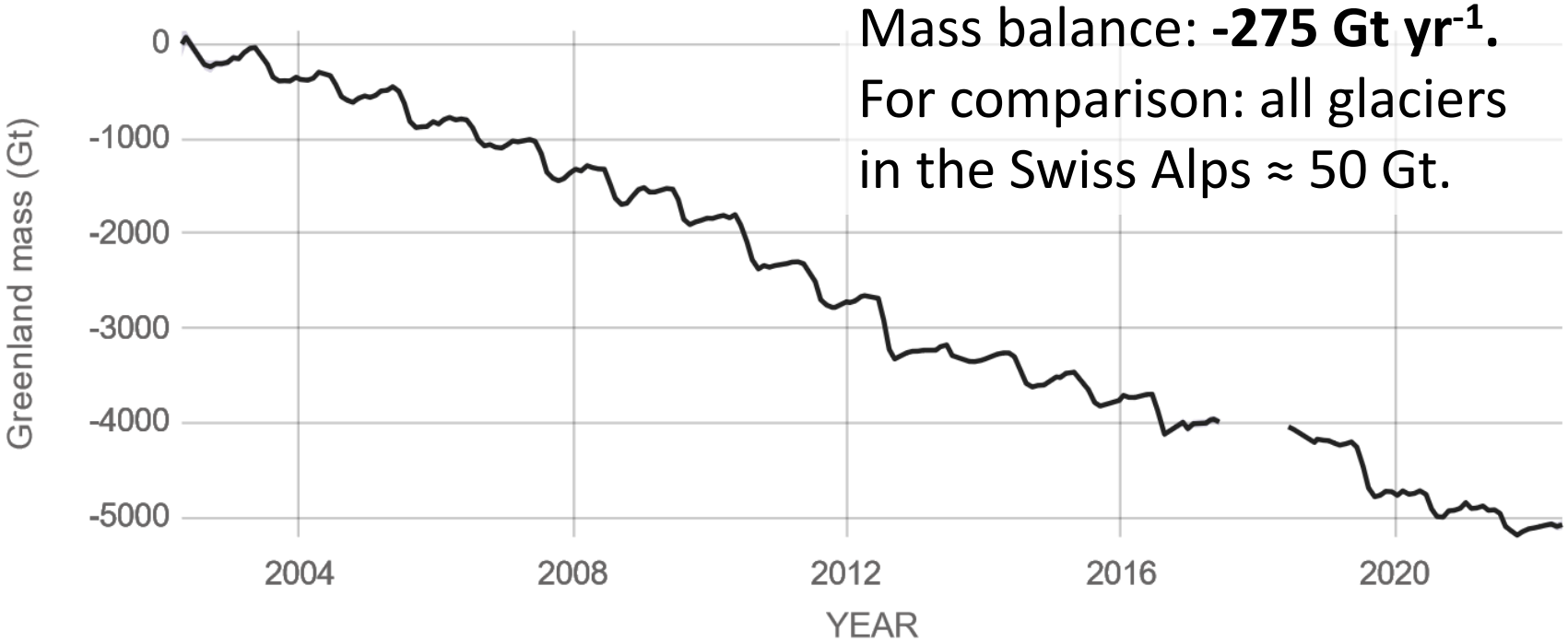
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Background | Greenland ice sheet mass loss

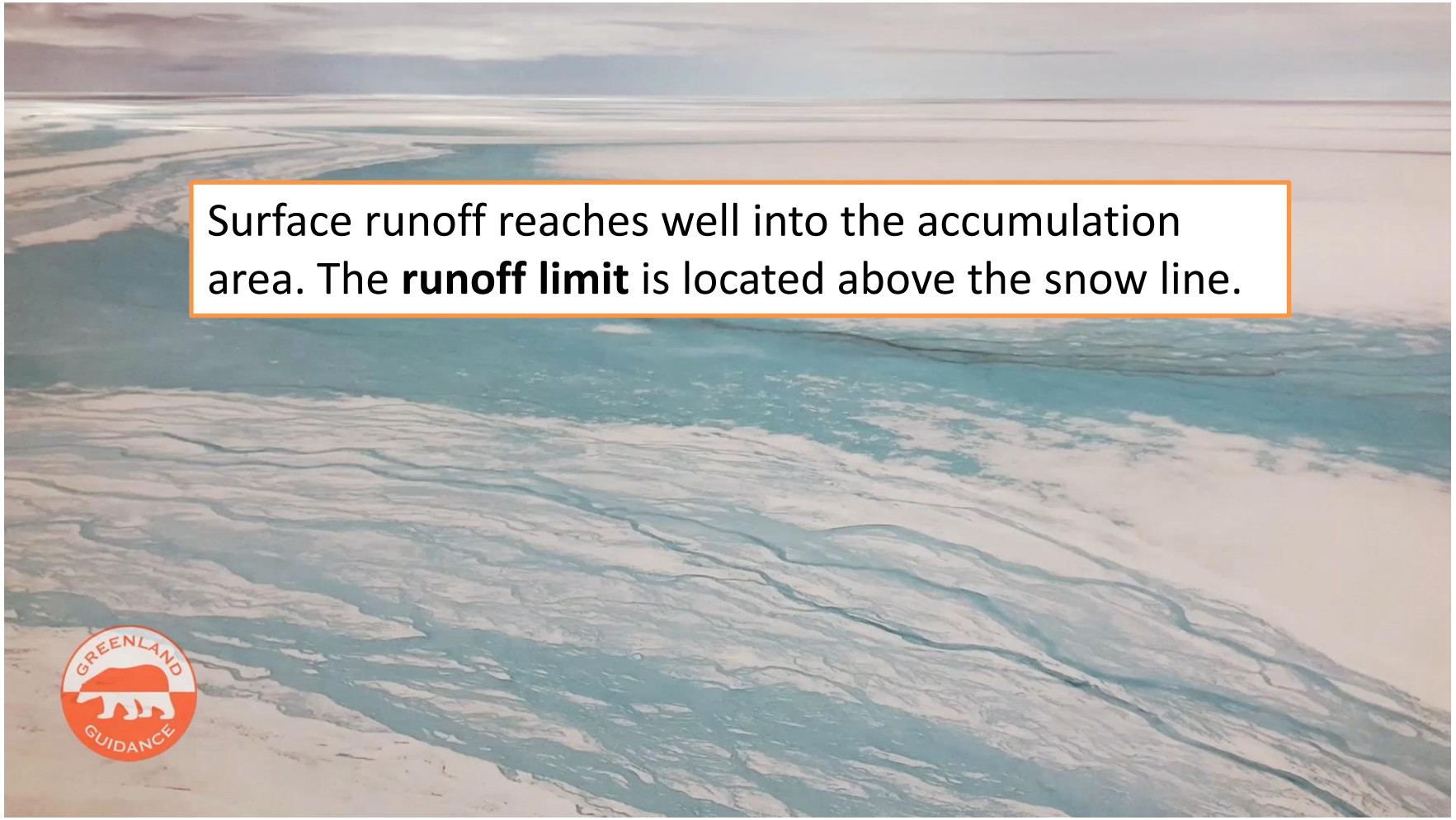


Greenland mass balance as measured from satellite gravimetry. *(Source NASA: https://climate.nasa.gov/vital-signs/ice-sheets/)*

Roughly 50% of the current mass loss of the Greenland ice sheet is **due to increased meltwater runoff.**

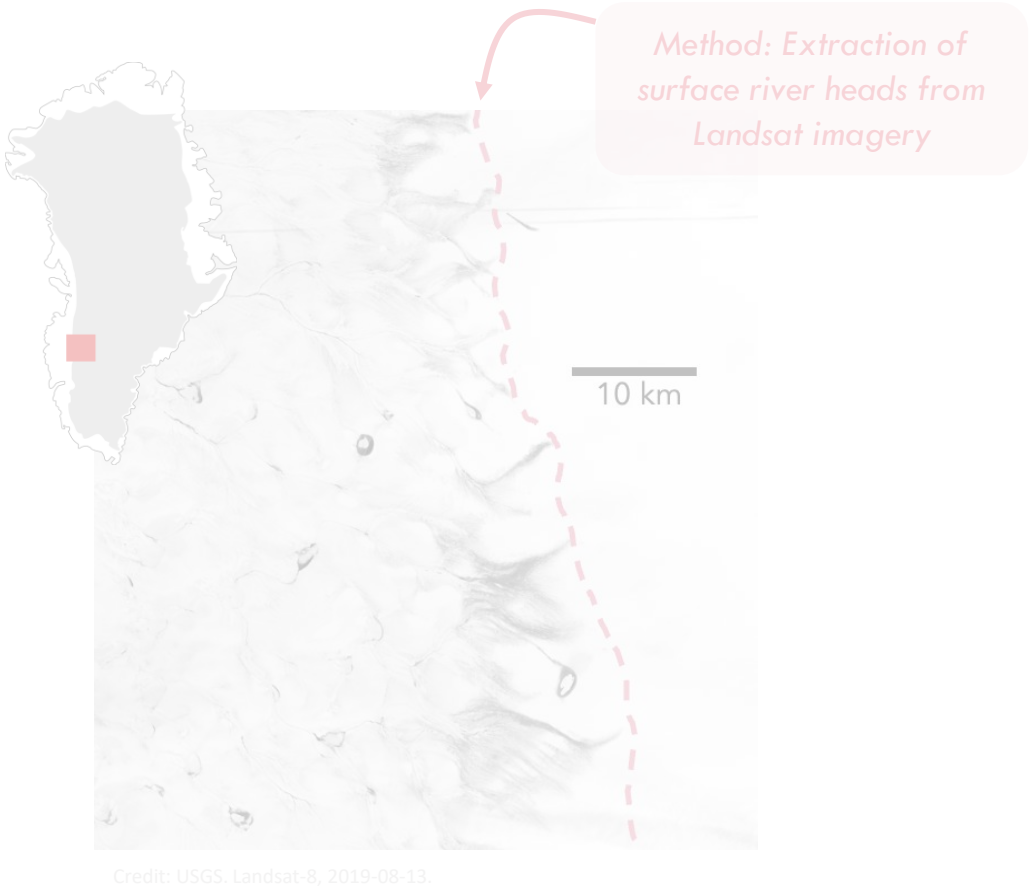
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Background | Greenland ice sheet surface runoff



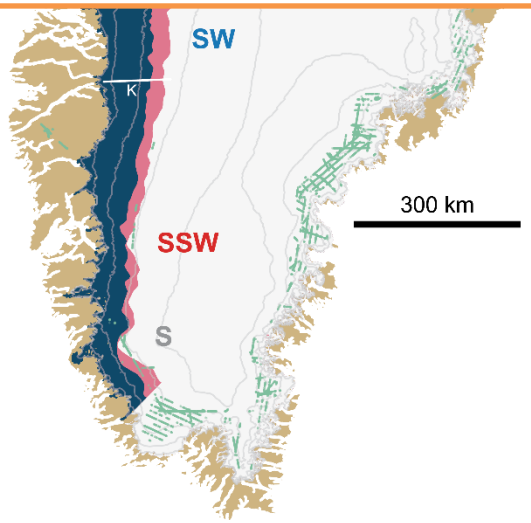
Surface meltwater ponding and discharge, 19 August 2021 at ~1740 m a.s.l. 67.0091 / -47.3019 *(Source: Dirk van As, Greenland Guidance)*

Background | Landsat mapping





Visible runoff area of the ice sheet **expanded by ~29%** between 1985 and 2020 (*Tedstone and Machguth, 2022*)

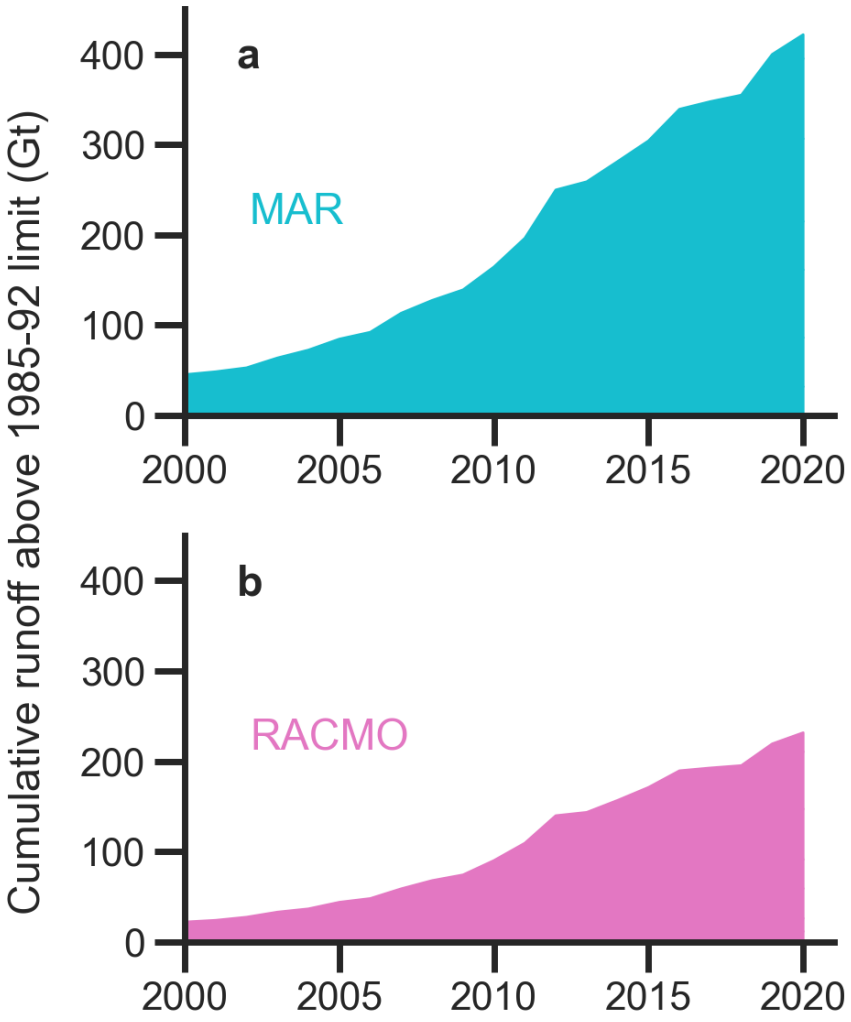


Extent of visible surface runoff, as mapped from Landsat *(Tedstone and Machguth, 2022): Runoff area* ***1985-1992 in dark blue,*** *additional runoff area* ***2013-2020 in pale red.***

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Background | Landsat mapping

- 5-10% of recent ice-sheet-wide mass loss comes from the expanded runoff area.
- **Regional climate models show large differences in runoff.**



Cumulative runoff above the 1985-92 runoff limit a) *MAR v3.11 (Fettweis et al., 2020)* ***b)*** *RACMO 2.3p2 (Noel et al., 2019). Tedstone & Machguth (2022)*

Background | RCMs and the runoff limit

Substantial RCM uncertainties around the runoff limit → **Relevance in a warming climate**

Landsat visible runoff limits have limited temporal resolution → **Use daily MODIS products** (*Machguth et al.*, 2022).

Method | MODIS mapping

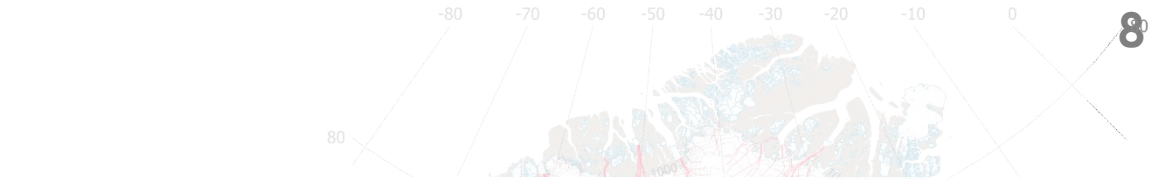
Greuell and Knap (2000): Focus on the **"slush limit",** i.e. the **transition from a zone of high spatial variability of surface albedo** (bright patches of snow alternating with darker slush and surface streams) **to an area of low spatial variability** (monotonous snow cover at higher elevations)

Daily MODIS products 500 m resolution (2000 to 2021)

- *MOD10A1: spatial variability of albedo and albedo*
- *MOD09GA: normalized difference water index for ice ($NDWI_{ice}$)*

Difference in spatial resolution between Landsat@30 m and MODIS@500 m (visible runoff limit 04.08.2013, 67 °N)

Method | MODIS mapping



2019/07/25 (DoY 206) | id102 | 68.32, -46.96 | Y_S: 1740 m a.s.l. | No data: 0.5 %

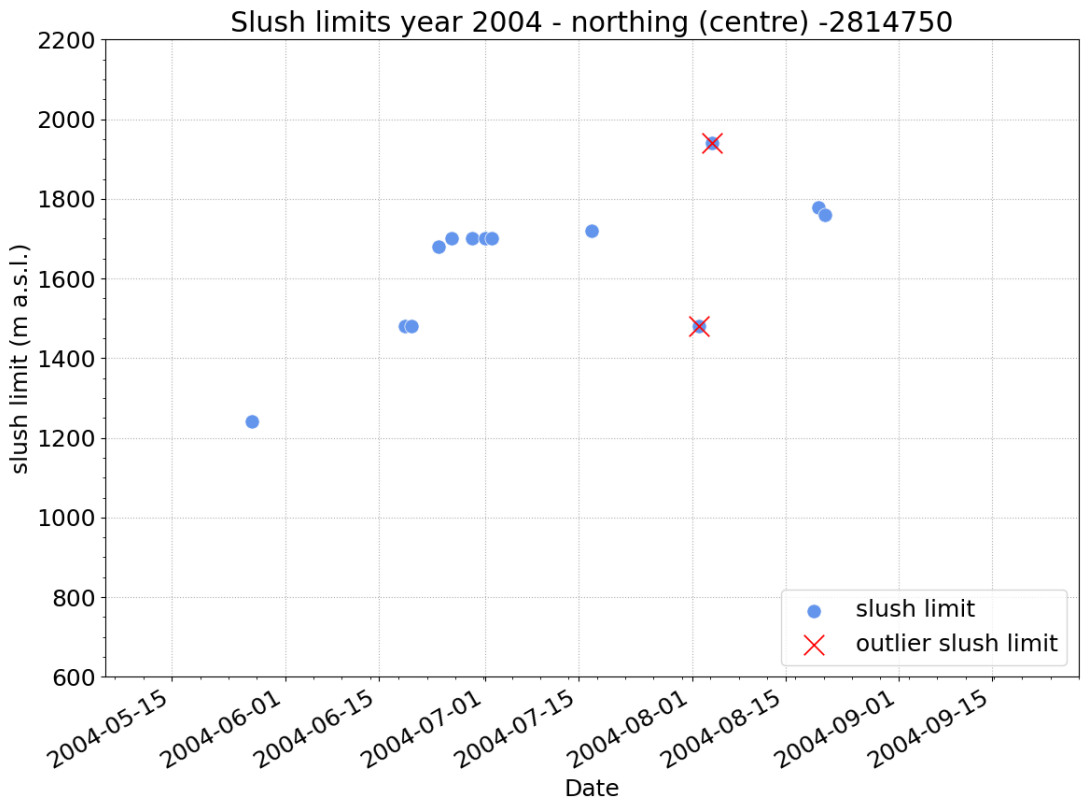
Basic approach of detecting the visible runoff limit *(slush limit)****, using MODIS***

The algorithm uses seven conditions to detect slush limits: **three main conditions** (as illustrated) and **four additional conditions** that mainly deal with data issues.

Cloud masks in MOD10A1 can be poor. Detection of the slush limit is often successful under partially cloudy conditions.

Method | MODIS mapping

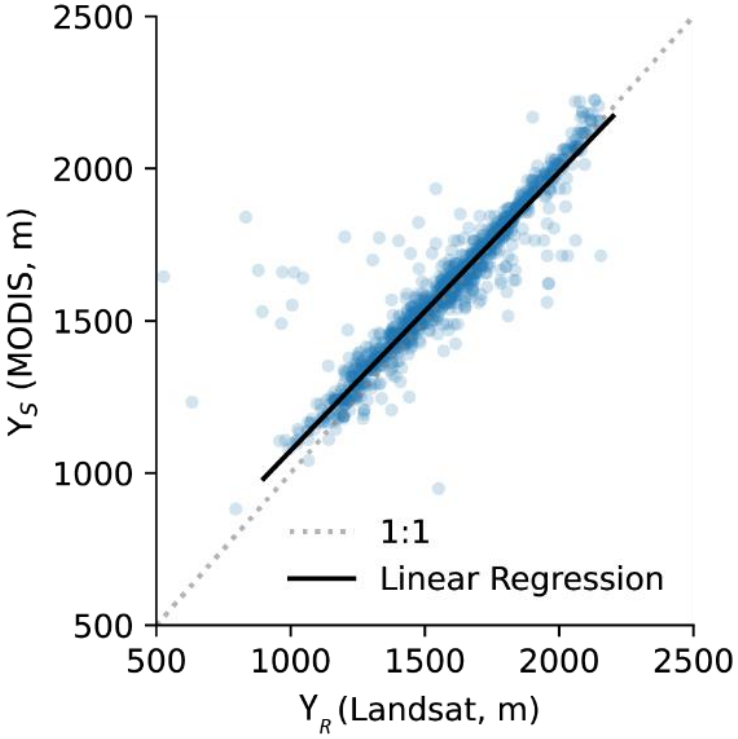
- **Erroneous detections occur** → Filtering candidates for conflicts (conflict = candidate is significantly higher or lower, deviation from general trend)
- **95% of visible runoff limit candidates are retained**

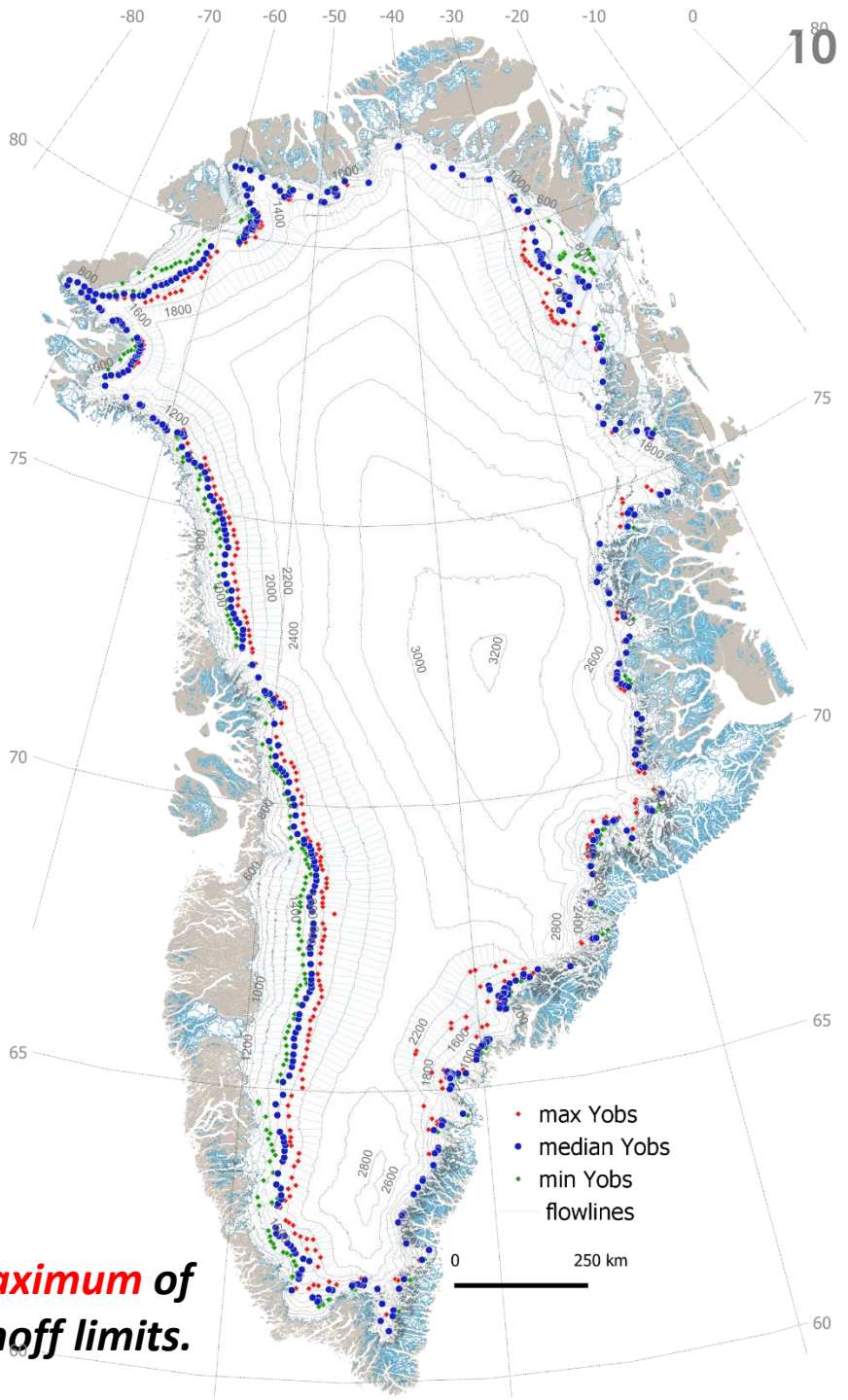


Outliers in detected visible runoff limits *(slush limit).*

Results | MODIS visible runoff limits

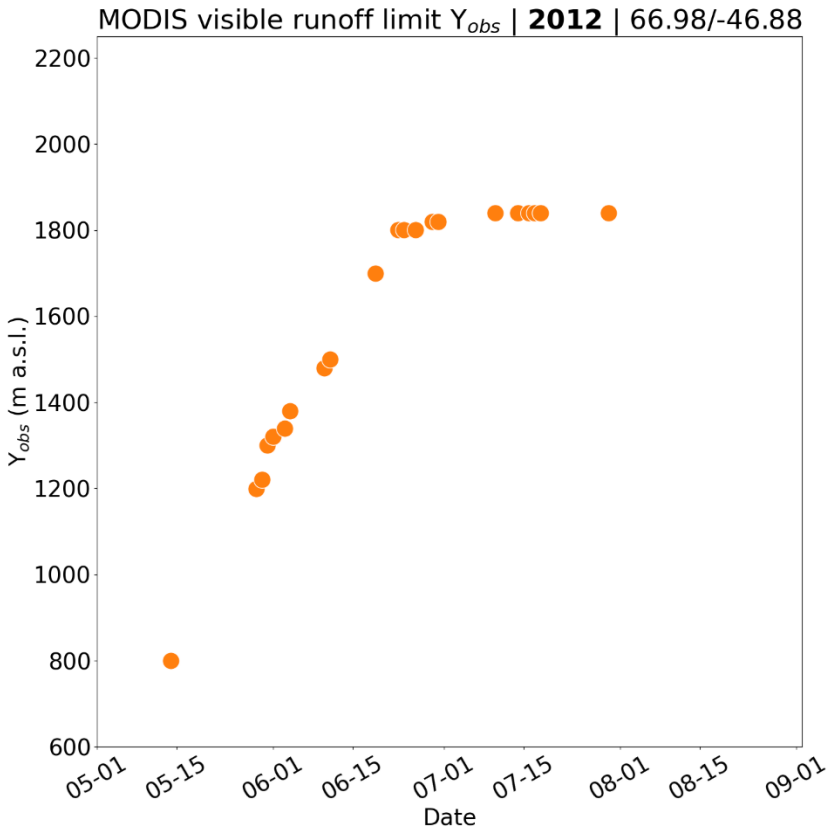
Landsat vs. MODIS runoff limits.
n = 1355, R^2 = 0.87 (R^2 = 0.96 when excluding failed comparisons)





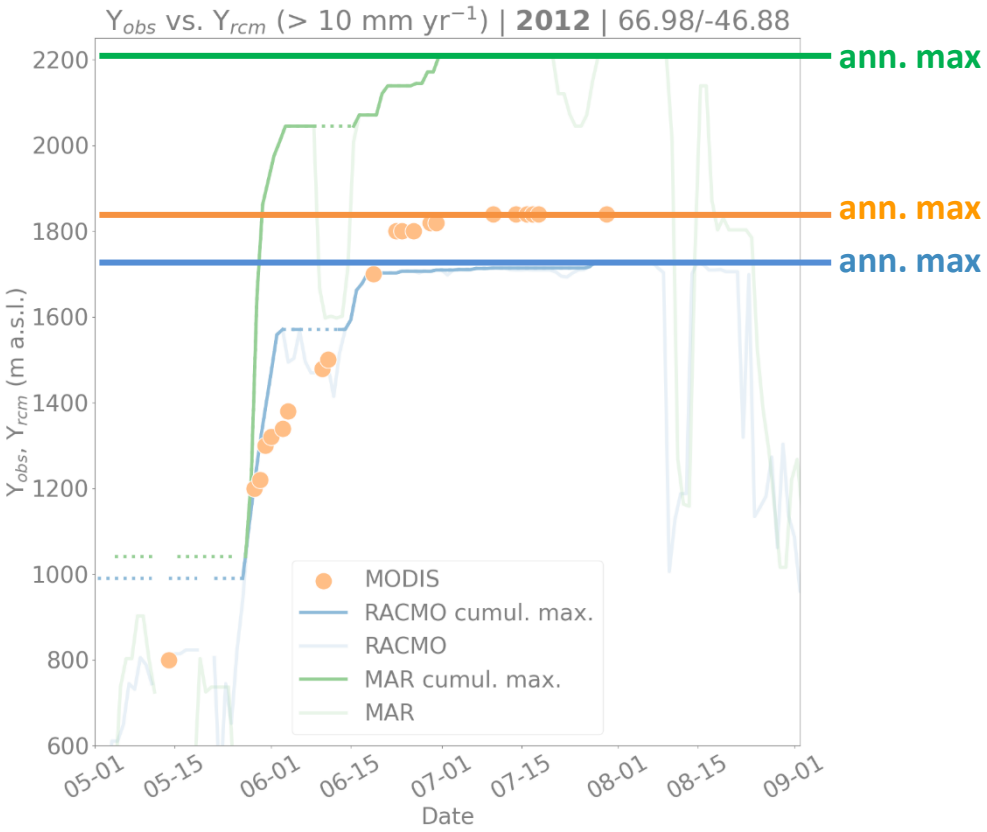
Minimum, median and maximum of annual maxima of MODIS vis. runoff limits.

Results | MODIS daily visible runoff limits



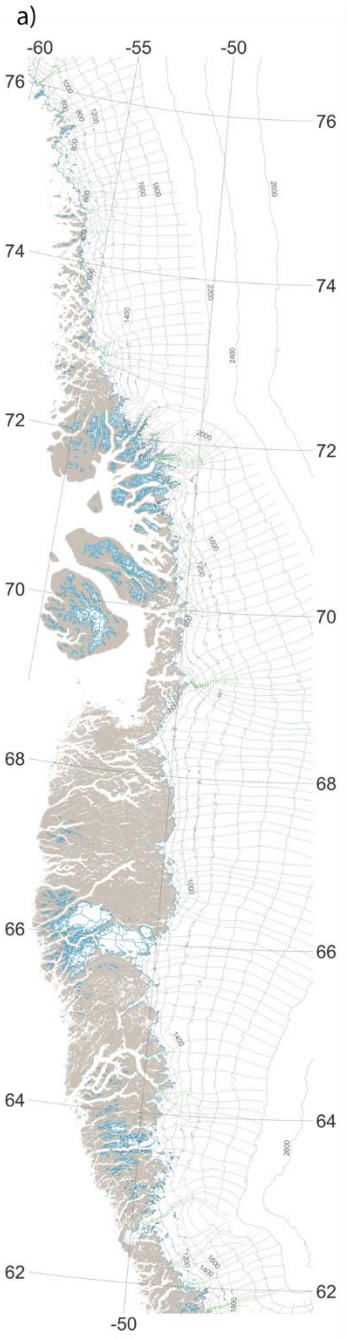
Seasonal evolution of the MODIS visible runoff limit, *year 2012, for one polygon in the south-west.*

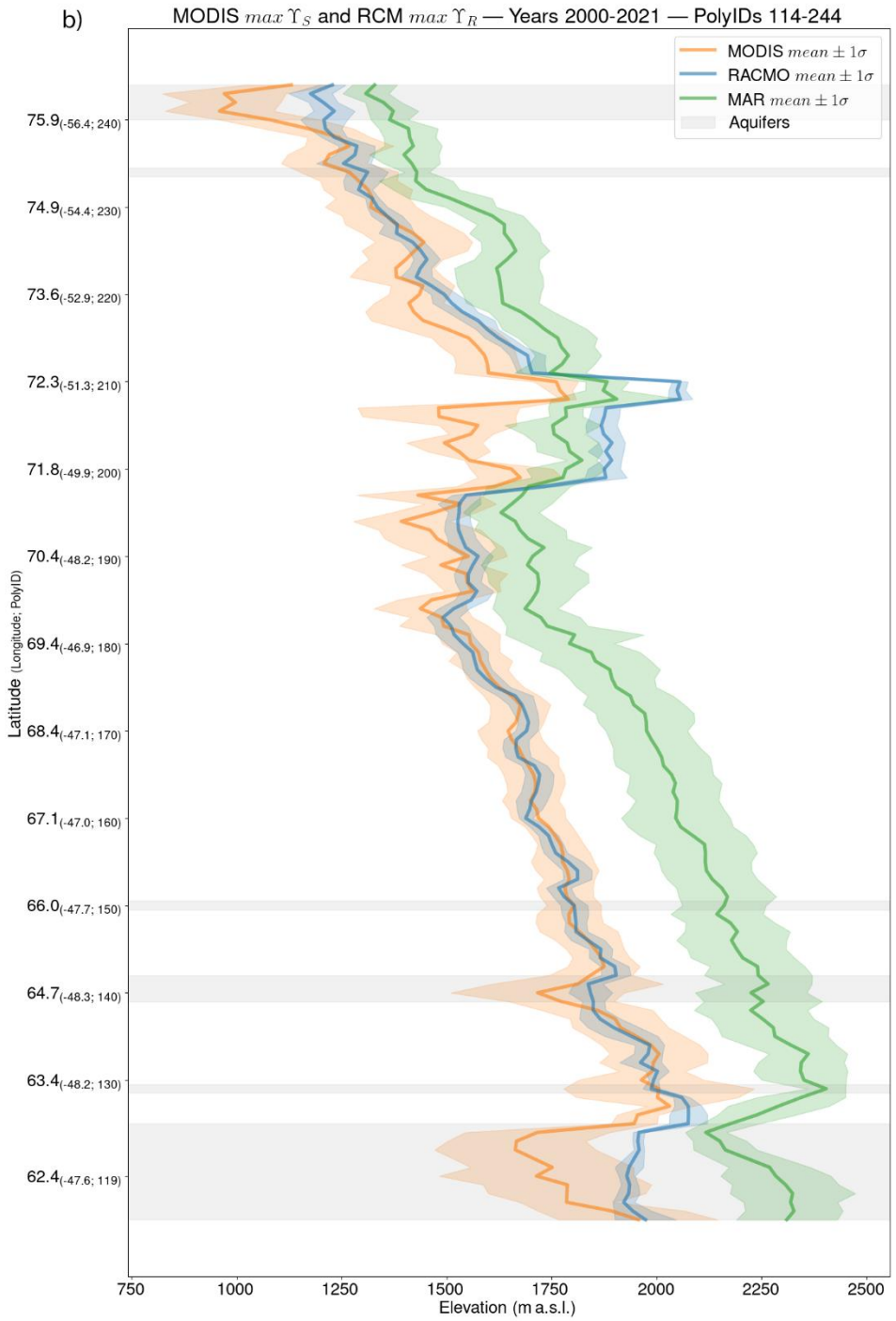
Results | Comparison MODIS to RCMs



MODIS, MAR *(v3.12.1, 5 km, ERA5)* ***and RACMO*** *(v2.3p2 FGRN055, 1 km (downscaled), ERA5):* ***Seasonal evolution of the (vis.) runoff limit,*** *year 2012, for one polygon in the south-west.*

Results | Comparison

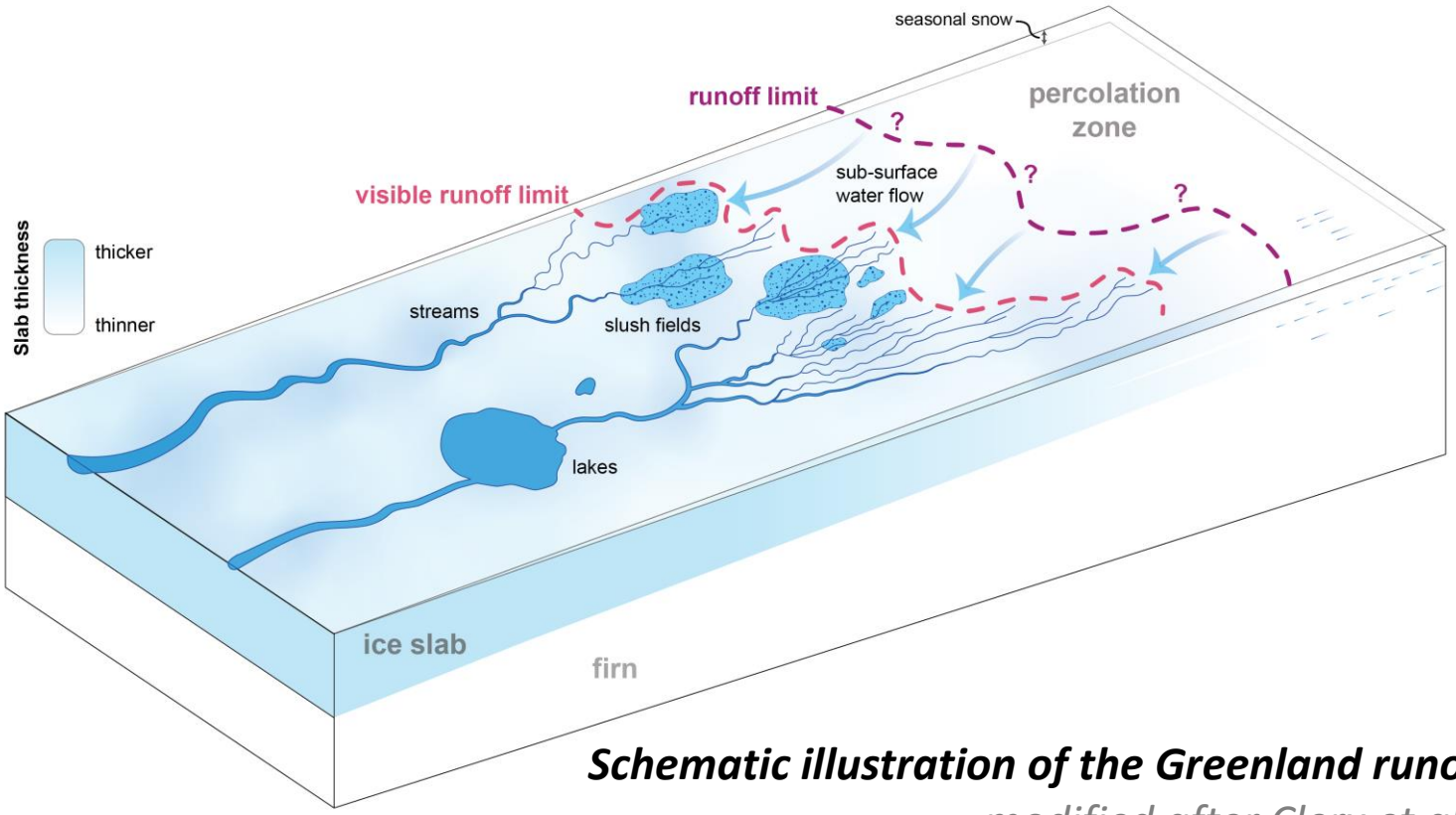




MODIS, MAR, RACMO: mean and stddev. of annual max. (visible) runoff limits of the west coast.

Discussion

- Landsat and MODIS mapping provide **novel datasets**
- In combination with RCMs → **Validating and improving projections of climate change impacts**
- In combination with field measurements and modelling → **Process understanding**



Schematic illustration of the Greenland runoff limit.
modified after Clerx et al. (2022)



















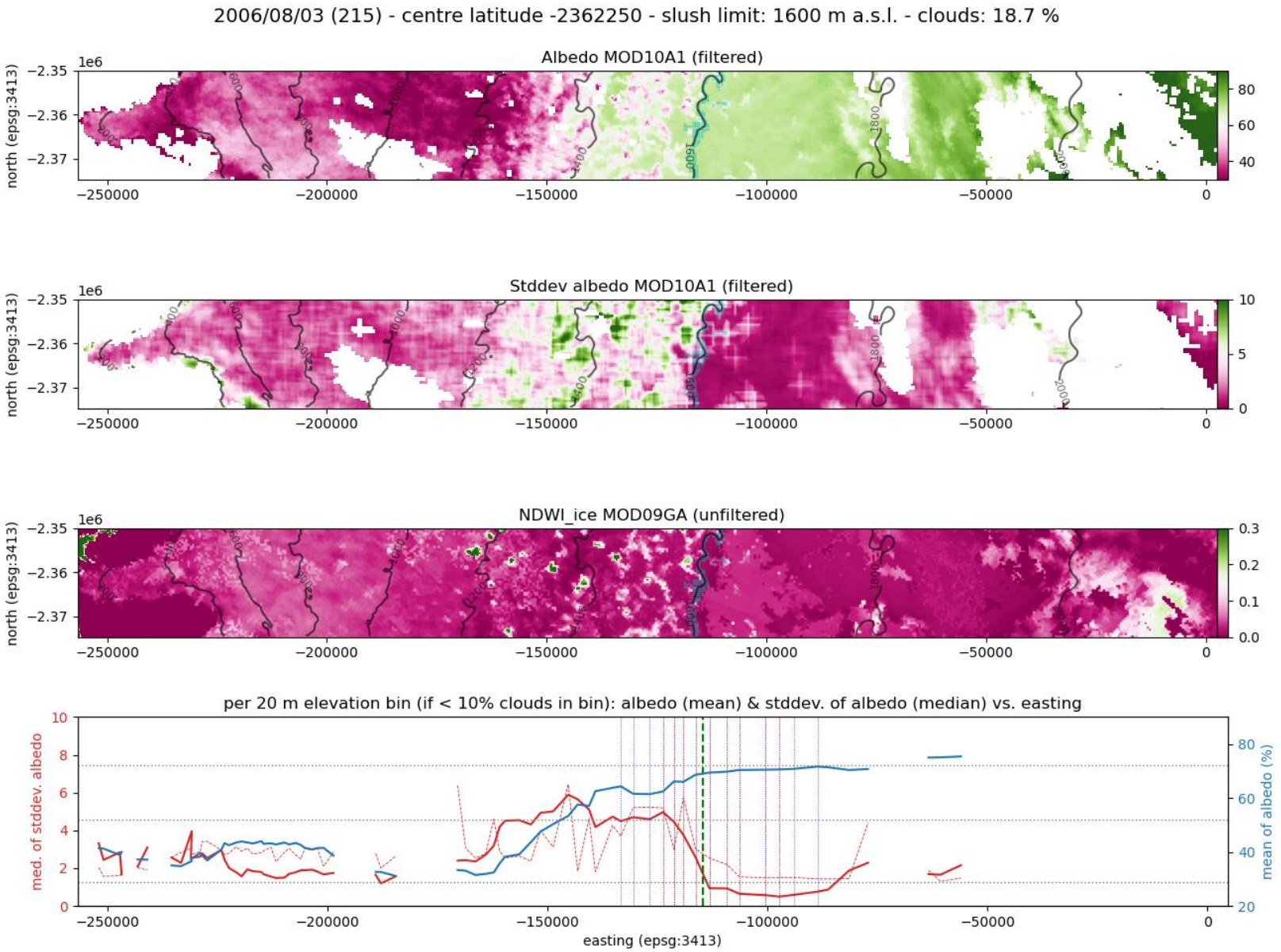




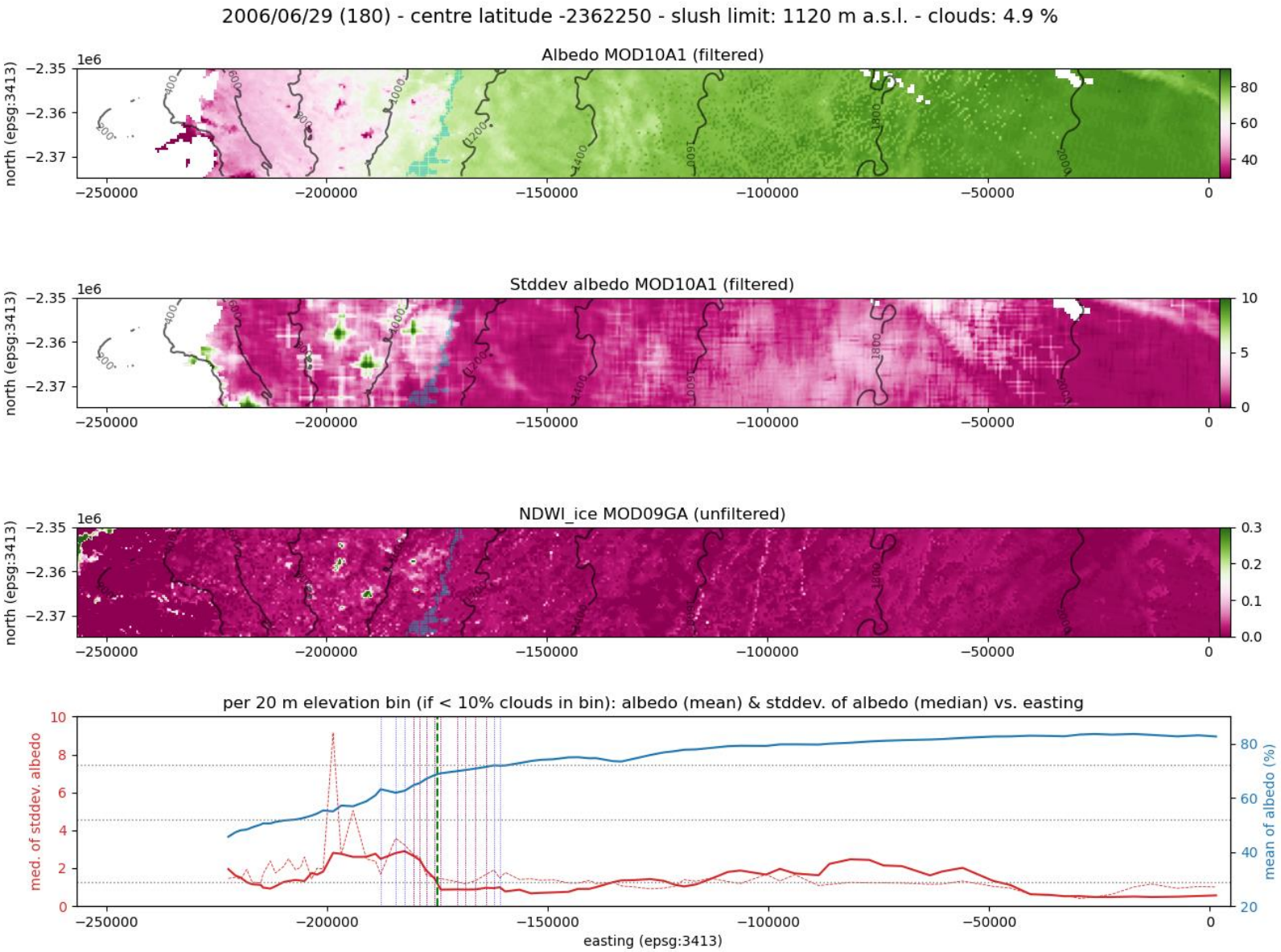


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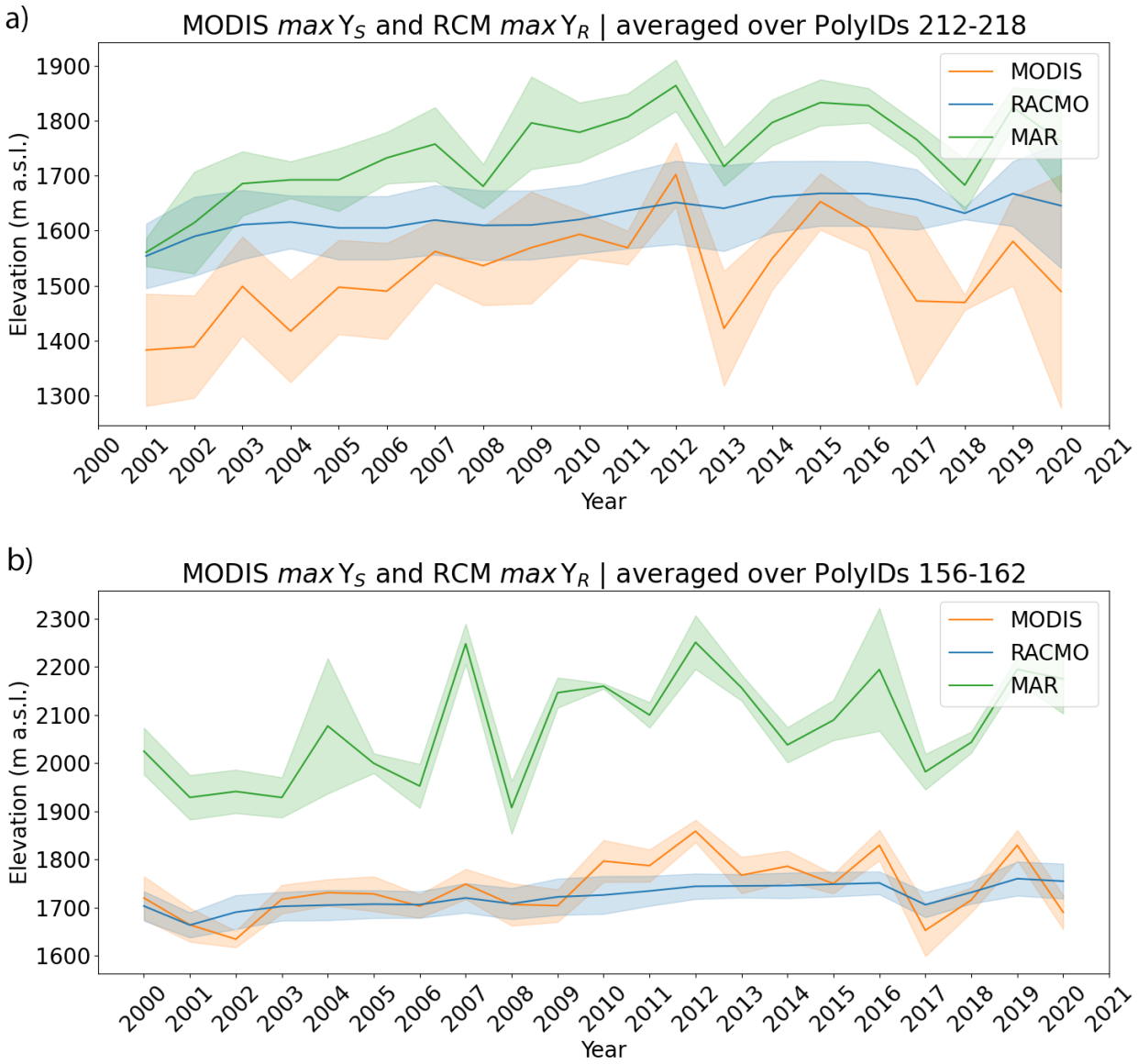
Appendix | MODIS cloud and data issues



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Appendix | Comparison MODIS to RCMs



MODIS, MAR and RACMO: 2000 to 2021 annual means of max. (vis.) runoff limits. a) *North-west coast;* ***b)*** *south-west coast*

Appendix | What are the reasons for the differences?

Evolution of subsurface density at the visible runoff limit *(KAN_U, west-coast, 67 °N, 1840 m).* ***a)*** *MAR, simulated 1980-2020;* ***b)*** *measured 2012 and 2017.*

