Ice loss in Patagonia and Tierra del Fuego glaciers during the first two decades of the 21st century

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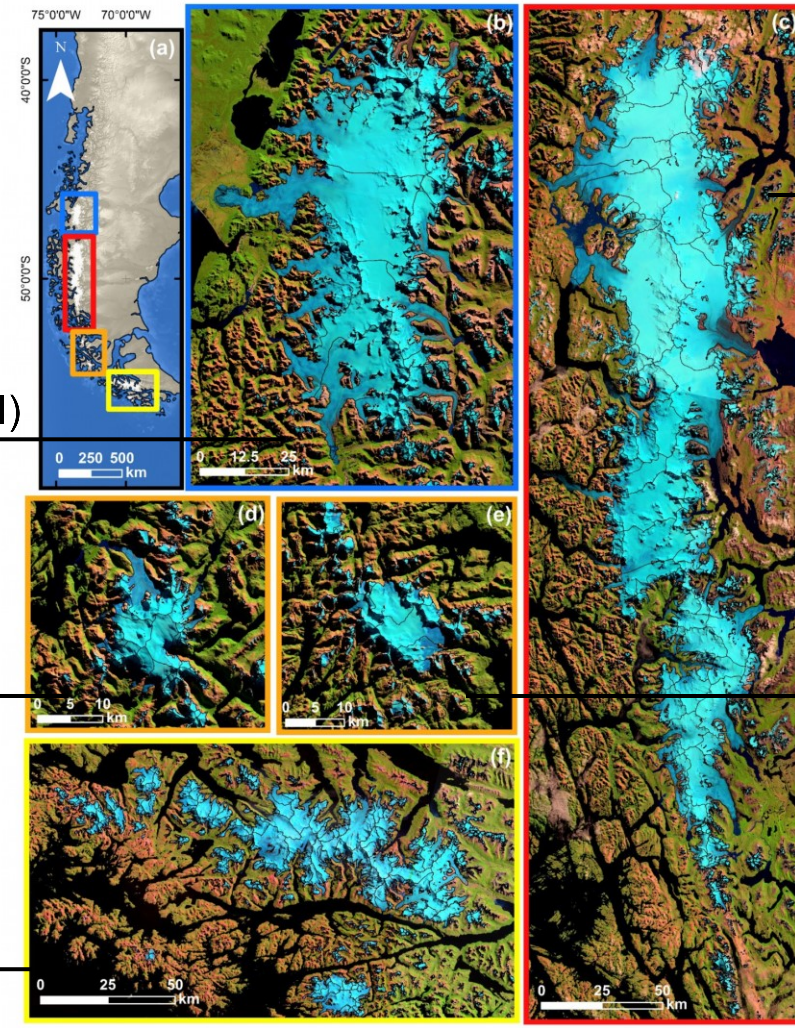


Southern Patagonia Icefield (SPI)

SPI is the largest temperate ice mass of the southern hemisphere with an area of ~13,000 km².

Northern Patagonia Icefield (NPI)

NPI is the second largest temperate ice mass with an area of ~4,000 km².

Gran Campo Nevado (GCN)

GCN covers an area of ~200 km².

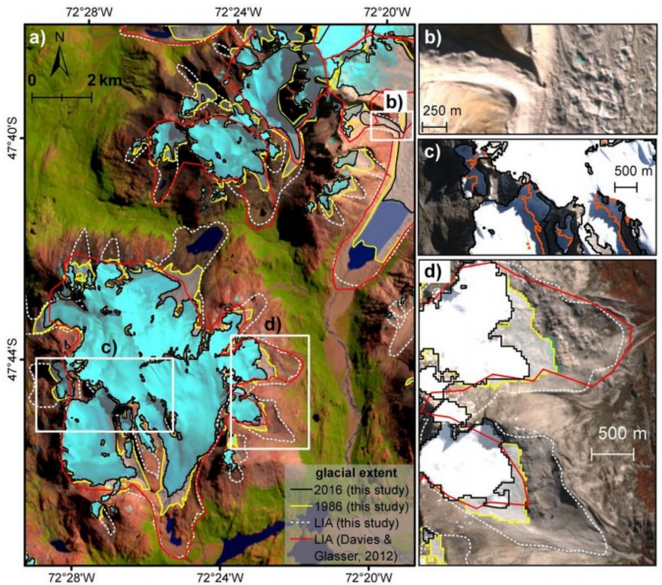
Isla Santa Inés (ISI)

ISI covers an area of ~200 km².

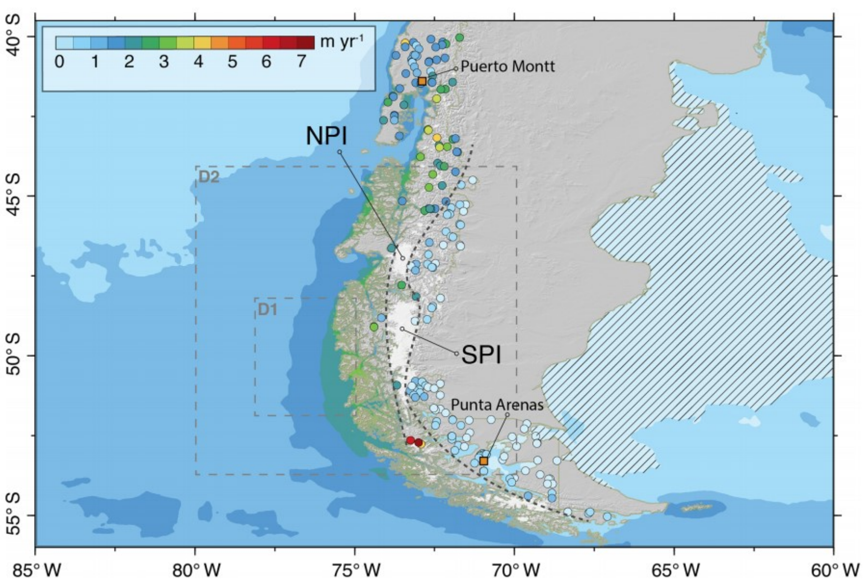
Cordillera Darwin (CD)

CD covers an area of ~2,350 km².

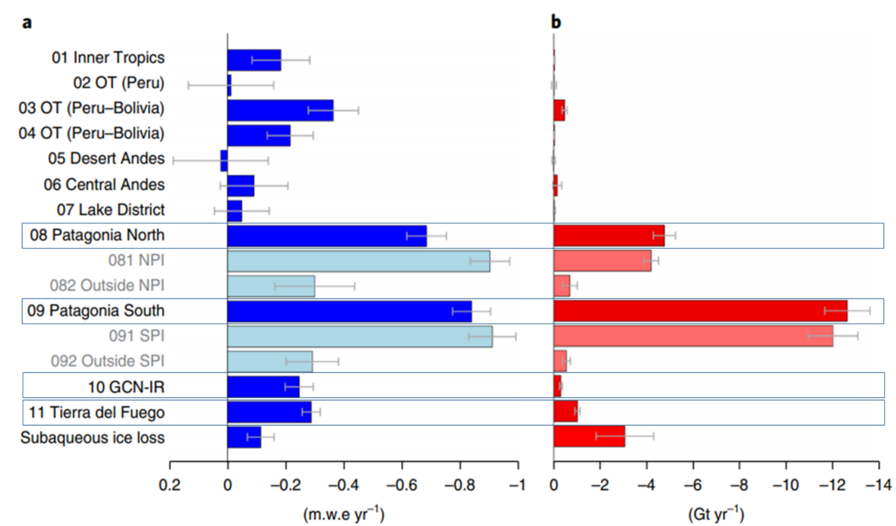
- Western Patagonia –between the pacific and austral Andes- is defined as hyper-humid region (Garreaud et al., 2014; 2018).
- High accumulation rates over the icefields (Schikowiski et al., 2013; Lenaerts et al., 2014; Schaefer et al., 2013,2015).
- Large glacier thinning and glacier retreat rates in Patagonia (Rivera et al., 2007; Falaschi et al., 2013; Meier et al., 2018; Malz et al., 2018; Foresta et al., 2018; Dussaillant et al., 2018, 2019; Braun et al., 2019; Abdel Jaber et al., 2019).
- Uncertainties about how glacier thinning and high accumulation can be explained by the combination of recent climate warming, atmospheric moisture transport and glacier adjustment during last decades (Schneider et al., 2020; Sauter et al., 2020).



Meier et al., 2018: Glaciers are retreating since LIA to 2016



Sauter, 2020: Precipitation distribution in Patagonia, based on weather station network of meterological Chilean service and water directorate (dots), GCN station (author stations).



Braun et al., 2018 -> Glacier mass balance of Patagonia and Tierra del Fuego Glaciers

Methods: Derive dh/dt from SRTM / TanDEM-X

SRTM:

C-band bistatic SAR

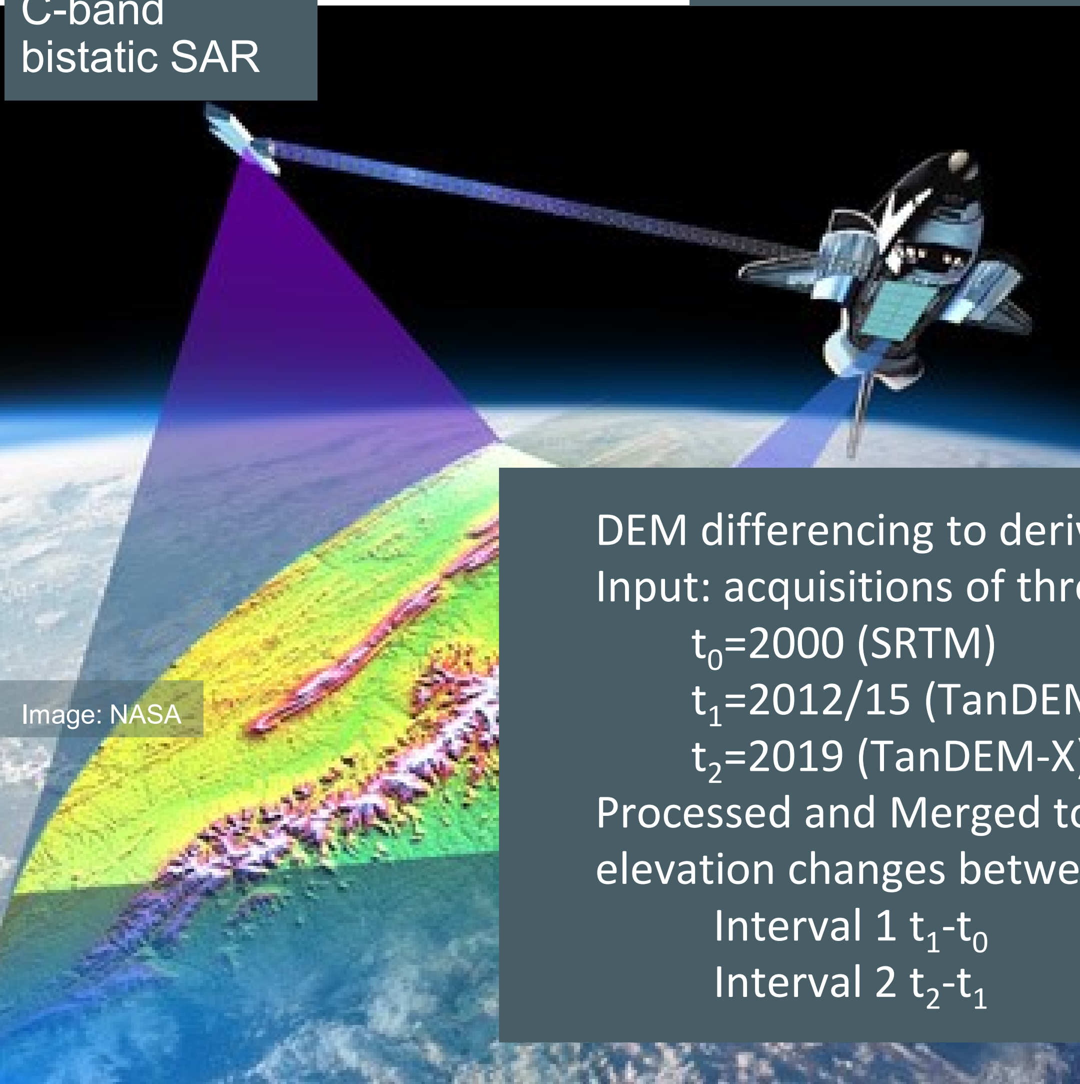


Image: NASA

DEM differencing to derive dh/dt

TanDEM-X:

X-band bistatic SAR

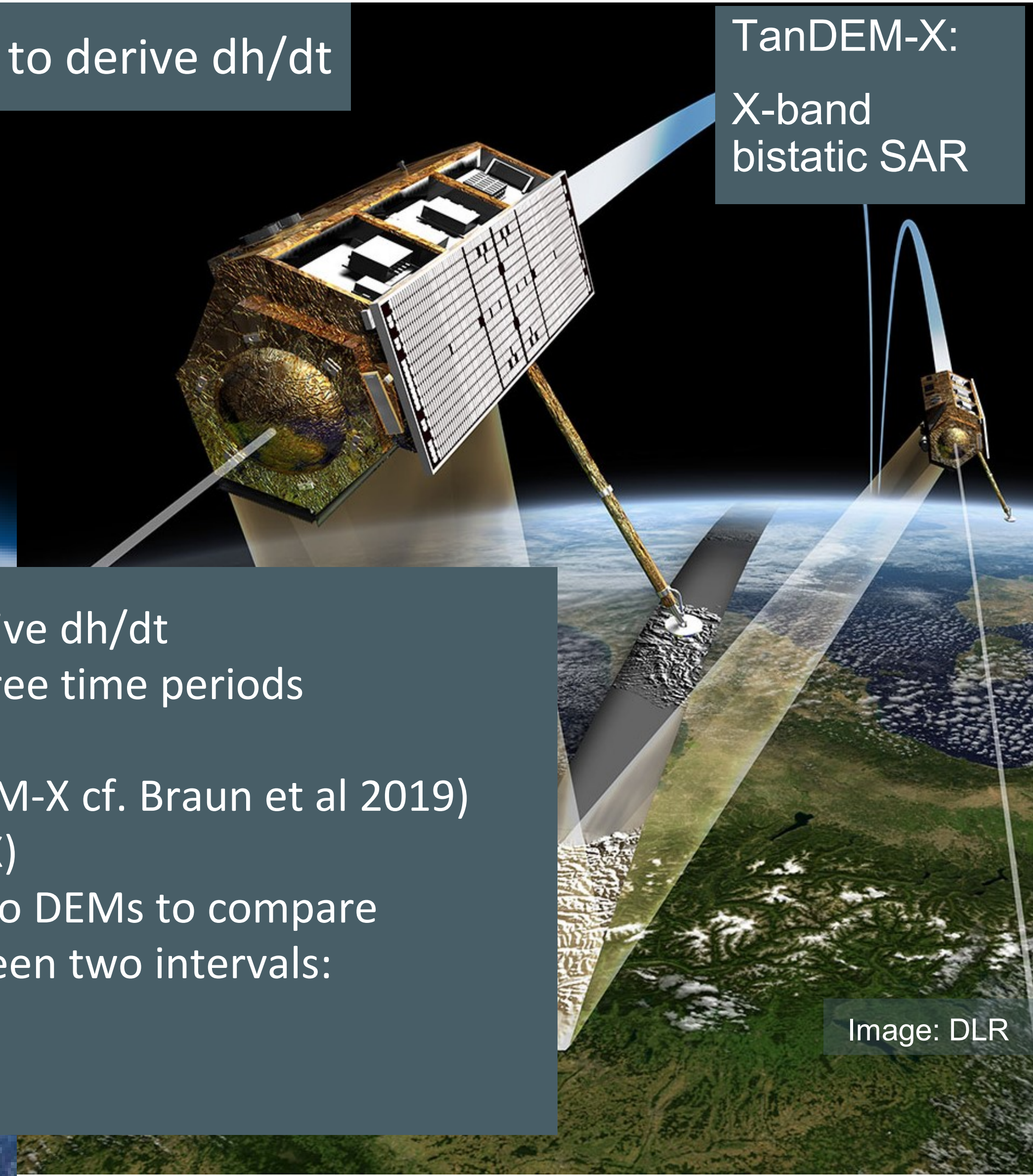


Image: DLR

DEM differencing to derive dh/dt

Input: acquisitions of three time periods

- t_0=2000 (SRTM)
- t_1=2012/15 (TanDEM-X cf. Braun et al 2019)
- t_2=2019 (TanDEM-X)

Processed and Merged to DEMs to compare elevation changes between two intervals:

- Interval 1 t_1-t_0
- Interval 2 t_2-t_1

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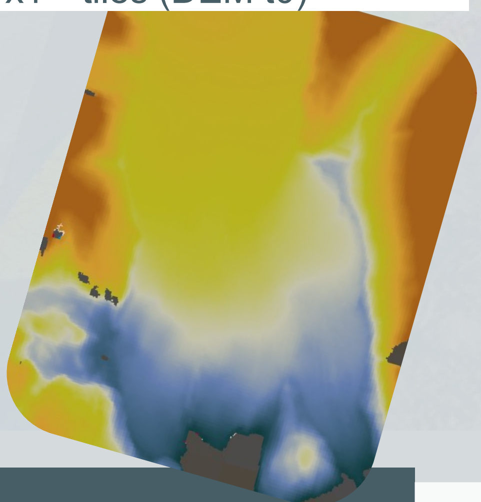
Methods: Derive dh/dt from input data

SRTM input:

DEM-product Version 3.0

Res: 1 arc sec, projected to 30 x 30 m pixel merges

- Create one projected, non void filled mosaics of 1x1° tiles (DEM t0)



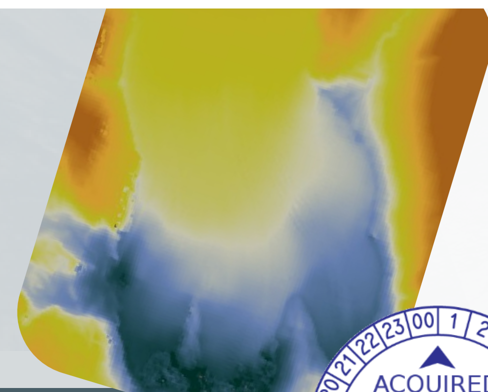
t_0 = 2000-16-02
mean mission date used

TanDEM-X input:

SLC-products (archive)

Res: processed to UTM projected reference (SRTM)

- Select scene pairs of aforementioned periods: two TanDEM-X mosaics (DEM t_1, DEMt_2)
- InSAR process DEMs
- Adjust and mosaic



t_1 =
t_2=

Timestamp selected as close as available to full year intervall from t_0

Dh/dt output:

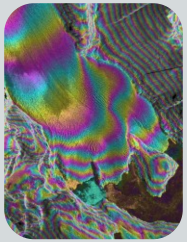
Maps of dh/dt:

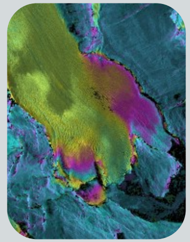
$$\frac{\text{Elev.}_{(\text{DEM } t1)} - \text{Elev.}_{(\text{DEM } t0)}}{t_1 - t_0}$$

$$\frac{\text{Elev.}_{(\text{DEM } t2)} - \text{Elev.}_{(\text{DEM } t1)}}{t_2 - t_1}$$

dh/dt datasets
Interval 1: Braun et al 2019
Interval 2: New Data

From TanDEM-X to elevation change datasets

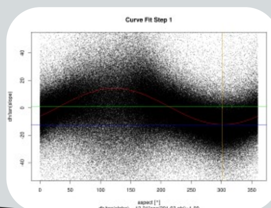




Differential InSAR processing:

Interferogram calculation with SRTM as reference model

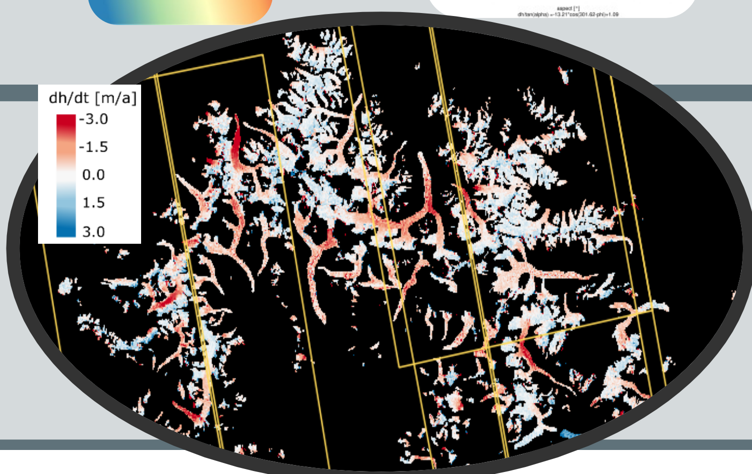
Phase to height conversion with differential phase, than readded to reference to get “absolute“ elevation results



Deramping and further corrections:

Resulting DEMs of previous step need further fitting to a reference elevation:

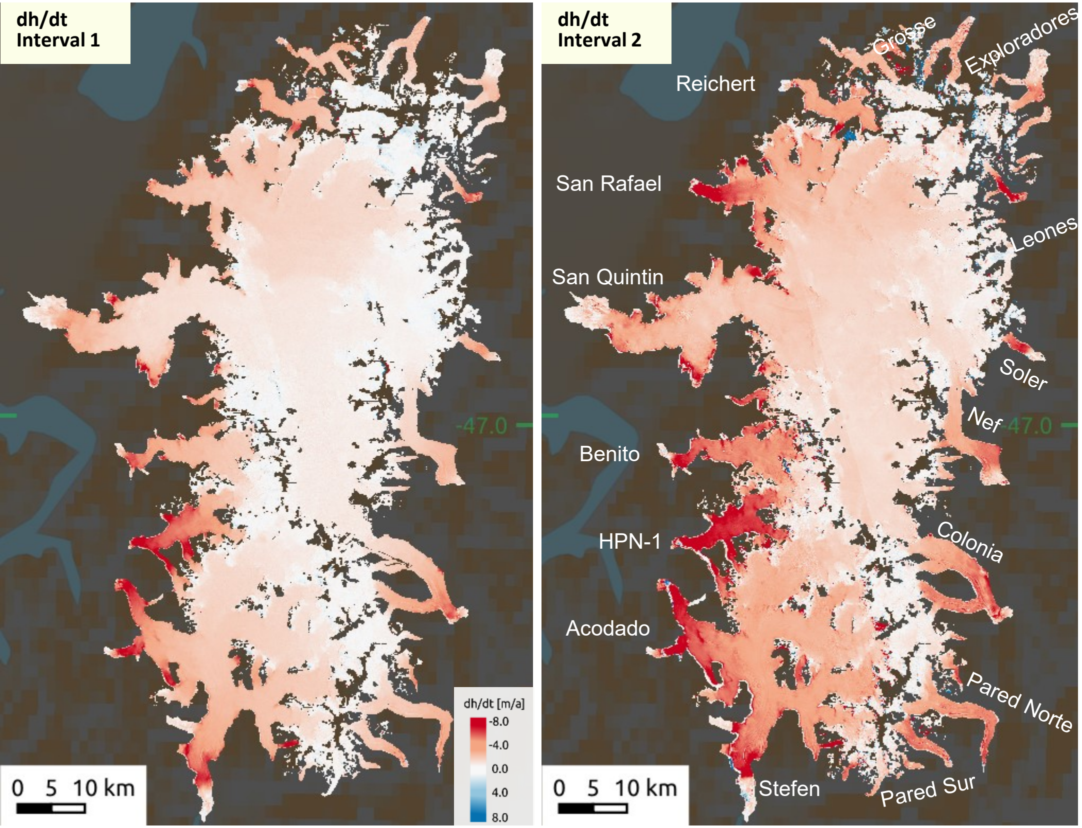
Minimizing systematic errors for each DEM strip following Nuth & Kääb 2011, Malz et al. 2018 procedure



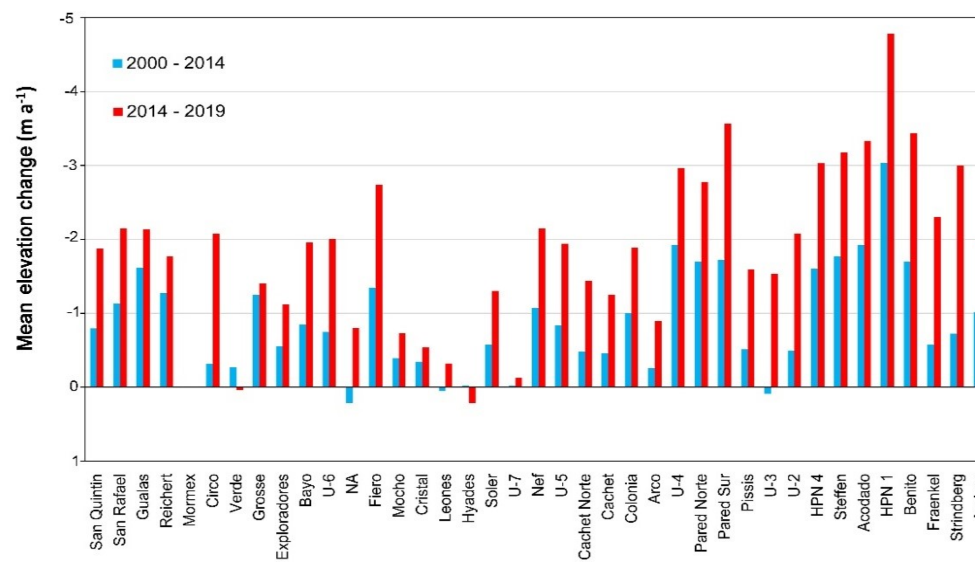
Mosaicing, differencing, masking and error assessment

Combining datasets to a regional results:

Northern Patagonia Icefield (NPI,) Southern Patagonia Icefield (SPI) , Gran Campo Nevado (GCN), Cordillera Darwin (CD)

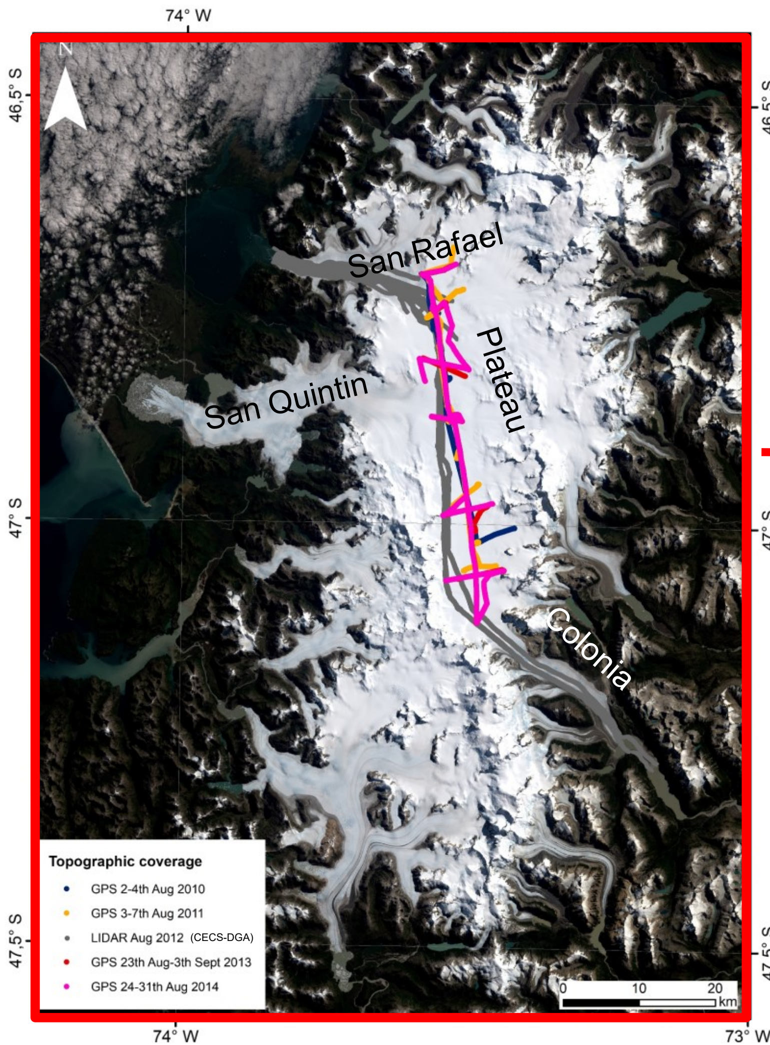


NPI	Elevation/mass balance/ volume change	Braun et al., (2019) 2000-2012/2015 (SRTM-TDX) (85% area measured)	2000-2014* (SRTM-TDX)	2014-2019 (TDX-TDX)
Density scenario 1 (0.850 ± 0.60 kg m^{-3})	mass balance rate (m w.e. a^{-1})	−0.85 ± 0.07	-0.92± 0.07	-1.91 ± 0.16
	mass change rate (Gt a^{-1})	−3.96 ± 0.32	-4.16 ± 0.32	-7.44 ± 0.61
Density scenario 2 (0.900 ± 0.60 kg m^{-3})	mass balance rate (m w.e. a^{-1})	−0.90 ± 0.07	-0.98 ± 0.07	2.02 ± 0.16
	mass change rate (Gt a^{-1})	−4.19 ± 0.32	-4.41 ± 0.32	-7.88 ± 0.62
	Volume changes (km^3 a^{-1})	−4.65 ± 0.17	-4.90 ± 0.14	-8.75 ± 0.36



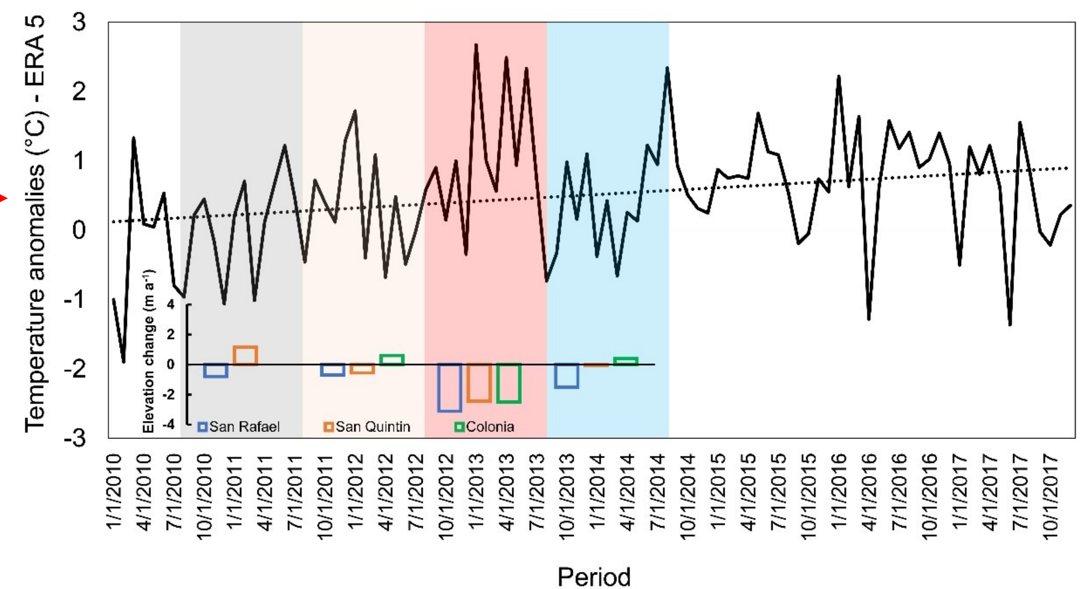
NPI results overview:

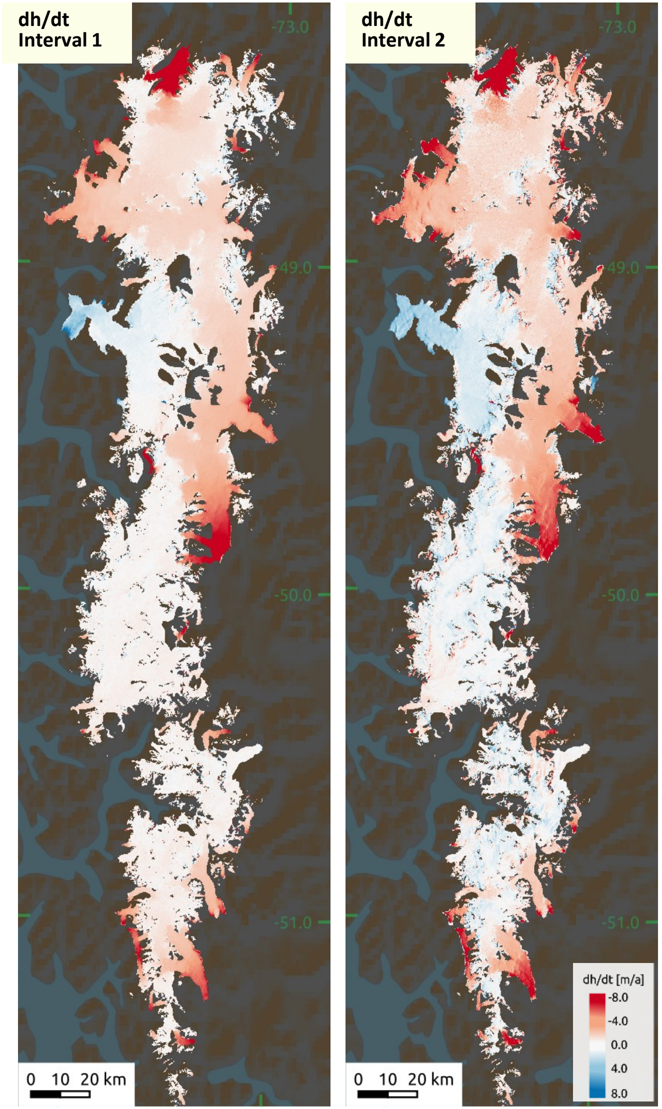
- Increase in thinning rates over almost all the glaciers.
- Glaciers located in the southern part of NPI present high rates between 2014-2019
- Significant increase of elevation thinning of HPN-1
- Increasing melt at the plateau



ERA5
area
retrieved

(Winter) short-term elevation change over the accumulation area of NPI (2010-2014) using GNSS and LiDAR. Between 2012-2013 all the analyzed glaciers present negative elevation changes, also correlated with high-temperature anomalies.

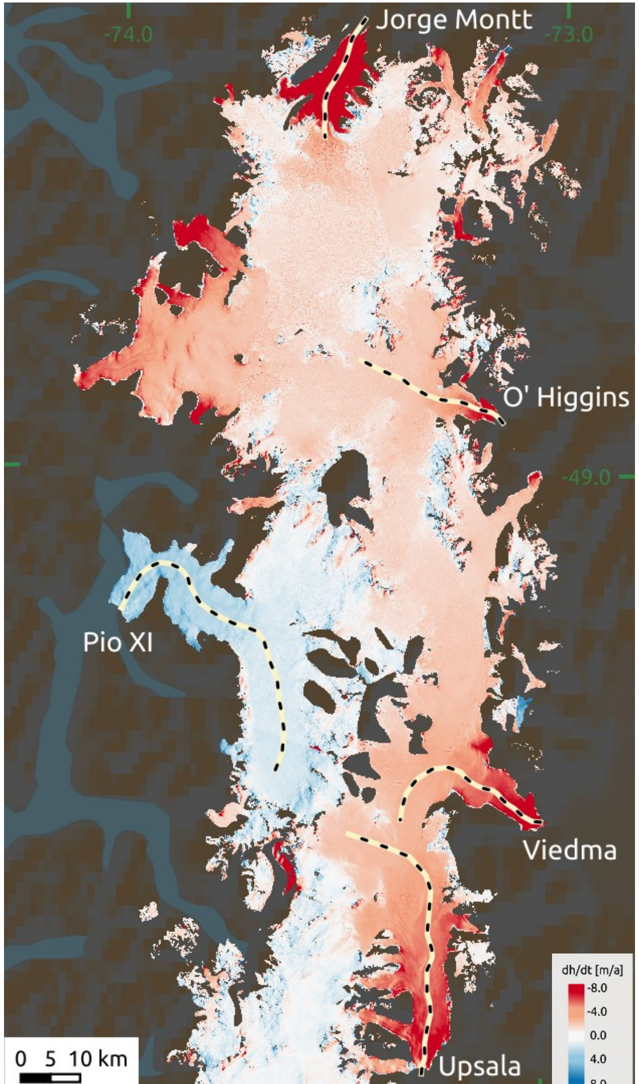


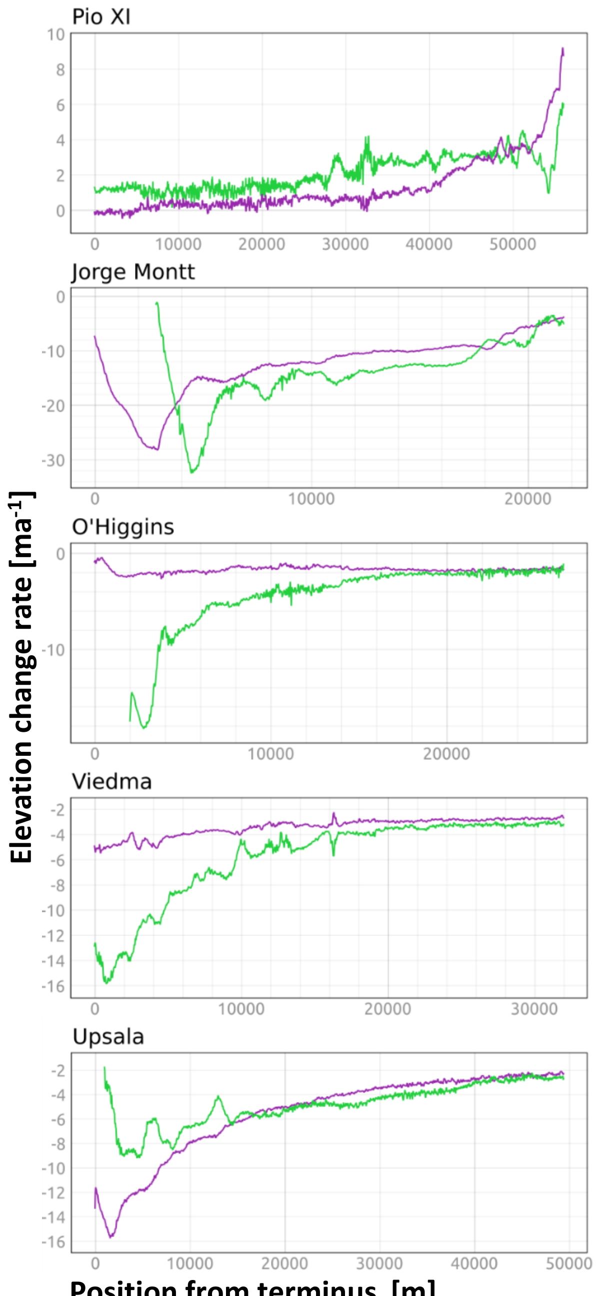


Comparison of Elevation and Volume Change rates of two intervals:

- Processes at outlet glaciers exceeding color bar – profile lines to analyze in detail on next slide
- Overall signal not as uniform as in NPI
- The highest areas of the plateau areas show different behavior along latitudes
- Overall mean volume change values is similar for both periods

SPI	Elevation/mass balance/ volume change	Period 1 Braun et al., (2019) Reduced to same Area as DEM t_2	Period 2 (TDX-TDX)
	Volume changes ($km^3 a^{-1}$)	-13.82 ± 0.56	-13.92 ± 0.78





Ice elevation change profiles of outlet glacier tongues: for Interval 1 (violet) and Interval 2 (green)

- Pio XI Glacier shows more positive elevation change than the first interval (Braun et al., 2019).
- Jorge Montt Glacier is retreating further at large rate; accelerated depletion
- O'Higgins and Viedma glaciers are drastically increasing melt at termini compared to earlier period: approx. 400%(!), only fading to previous rates at 15 km
- Upsala Glacier is recovering from strong loss on approx. the last 20 km to significantly smaller rates

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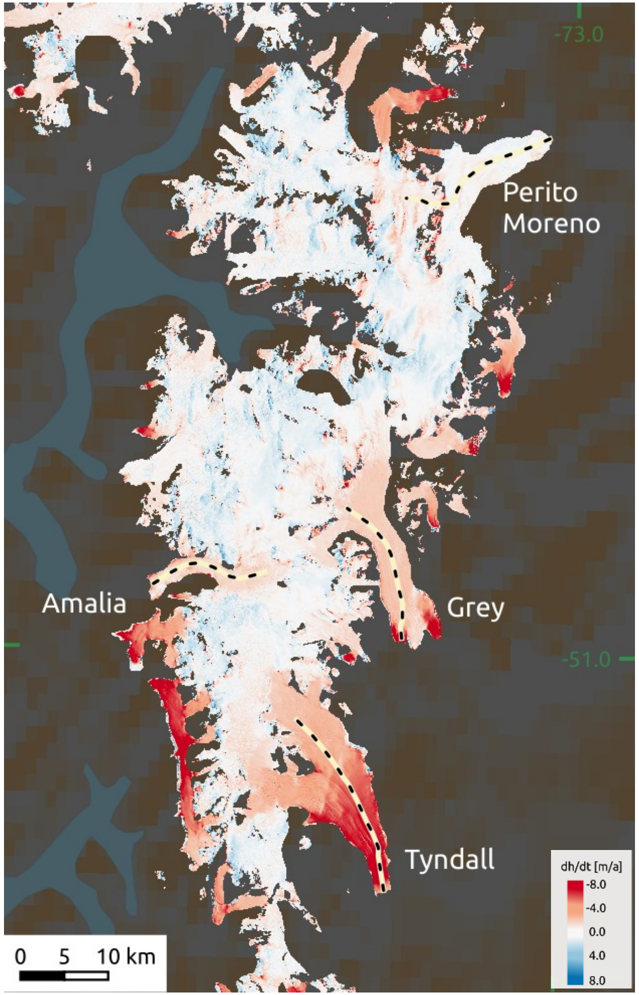

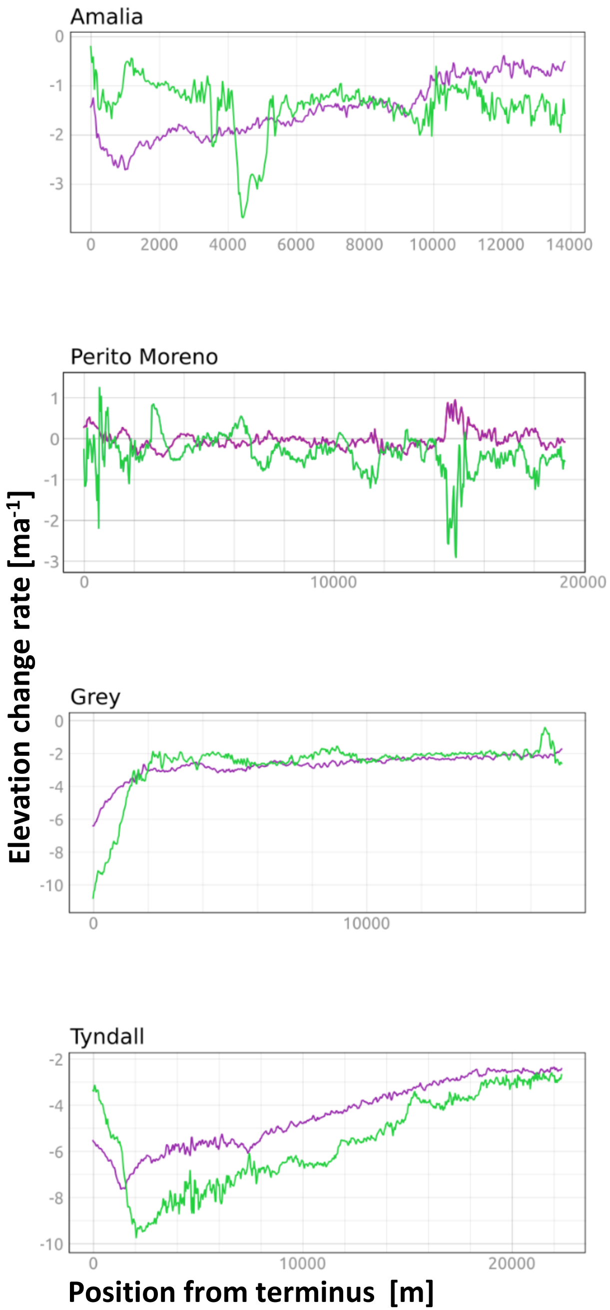

Ice elevation change profiles of outlet glacier tongues: for Interval 1 (violet) and Interval 2 (green)

- Amalia undergoing dynamic adjustment of ice surface elevation for Interval 2
- Perito moreno Glacier is relatively stable
- Grey Glacier is showing depletion increase only on last 2 km, but at approx. +50%
- Tyndall Glacier is losing elevation at higher rate on last 5 km (40-30%).

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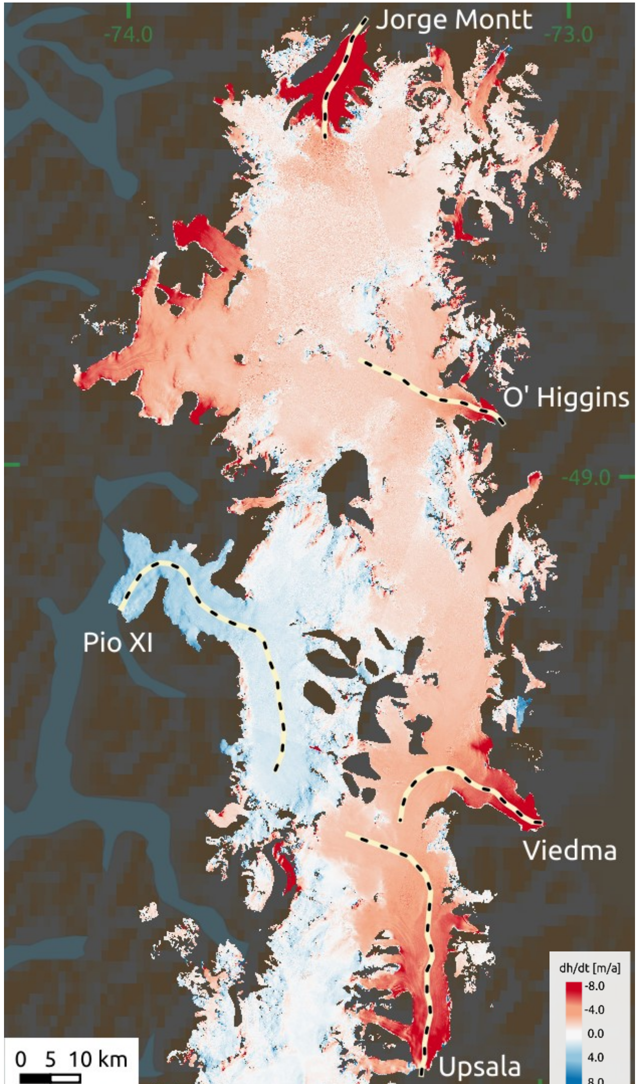
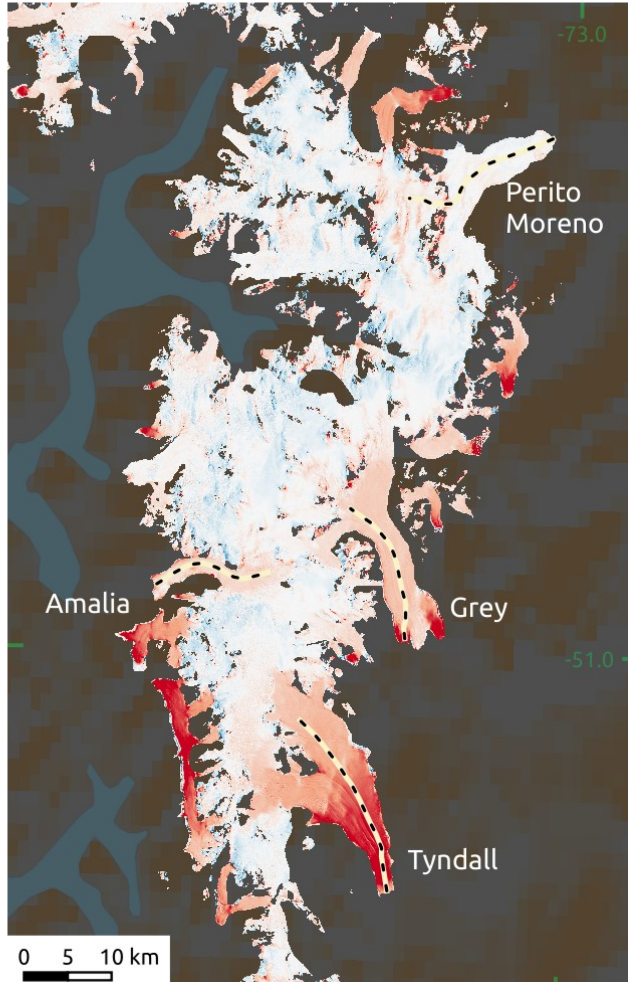
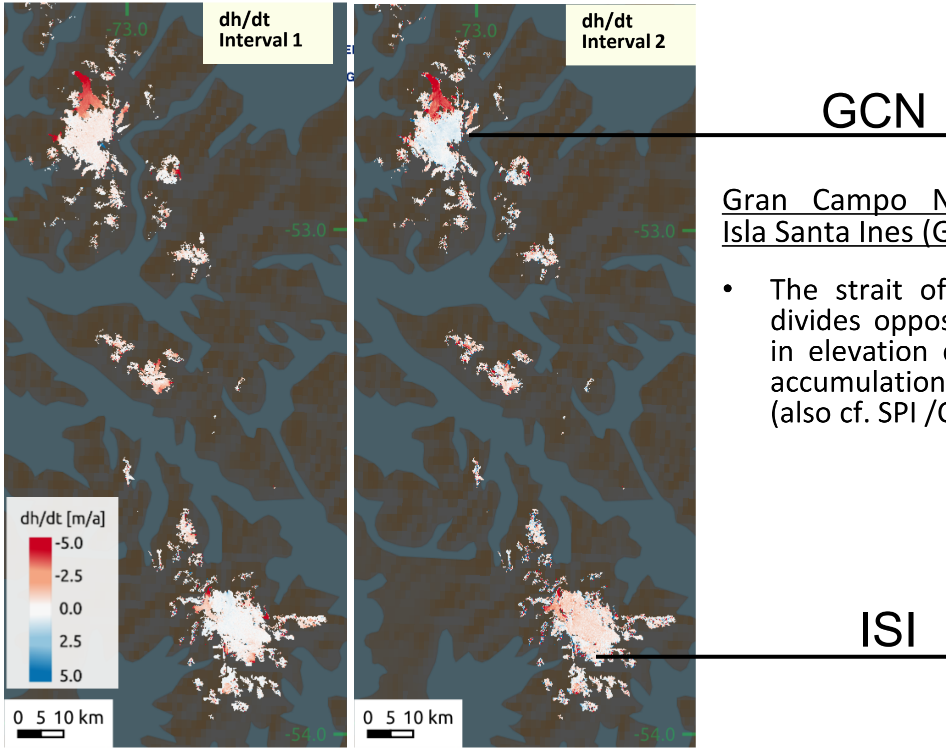




SPI results overview:

- Outlet glaciers are reacting heterogeneously and do not all continue recorded behavior for previously studied period (cf. Braun et al 2019)
- Increase in depletion dominant for outlet glaciers and also for northern SPI “accumulation“ areas (Pio XI Glacier contrasting this picture)
- Central and southern plateau show positive change rates
- Overall similar mean elevation change rate for both periods.

SPI	Elevation/mass balance/ volume change	Period 1 Braun et al., (2019) Reduced to same Area as DEM t_2	Period 2 2013-2019 (TDX-TDX)
	Volume changes ($km^3\ a^{-1}$)	-13.82 ± 0.56	-13.92 ± 0.78

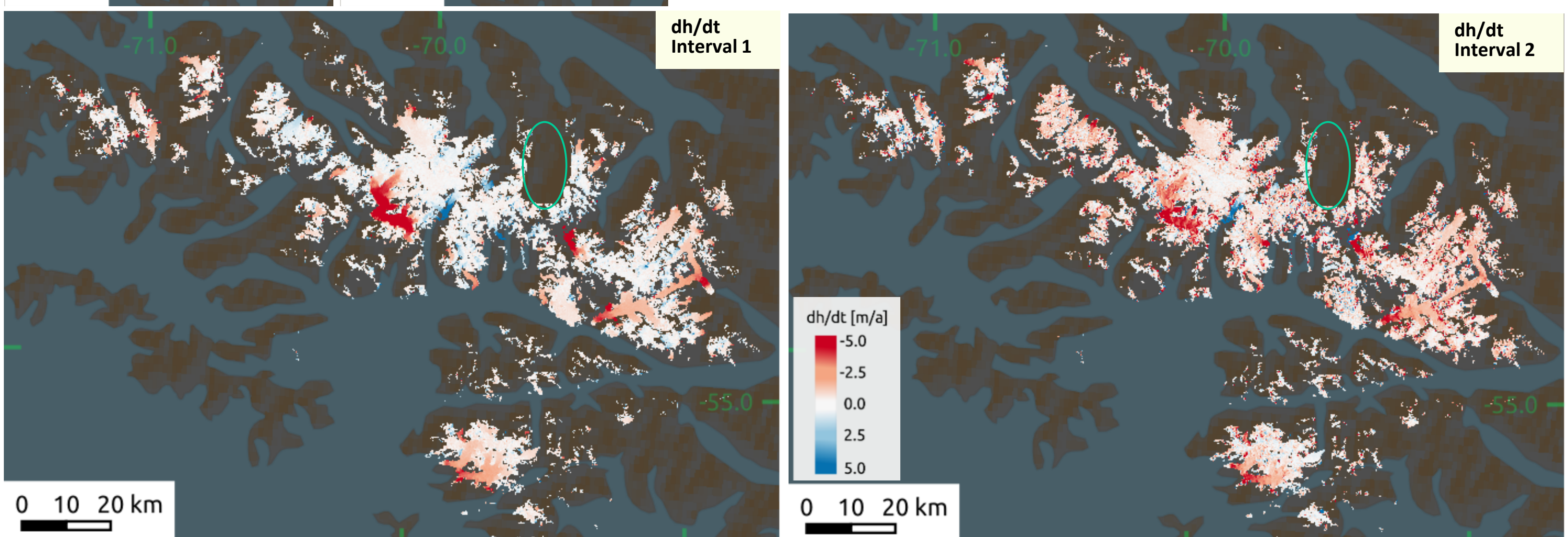


Gran Campo Nevado & Isla Santa Ines (GCN)

- The strait of Magellan divides opposite trends in elevation change on accumulation areas (also cf. SPI /CD region)

GCN	Elevation/mass balance/ volume change	Braun et al., (2019) 2000-2012/2014 (mean 2013 (SRTM-TDX) (89% area measured)	2013-2019 (TDX-TDX)
	Volume changes ($km^3\ a^{-1}$)	-0.34 ± 0.06	-0.47± 0.09

CD	Elevation/mass balance/ volume change	Braun et al., (2019) 2000-2011/2014 (mean 2013) (SRTM-TDX) – (82% area measured)	2013-2019 (TDX-TDX)
	Volume changes ($km^3\ a^{-1}$)	− 1.13 ± 0.10	-2.63 ± 0.15



Cordillera Darwin (CD)

- Remarkable increase in ice elevation loss on studied area
- Overall preliminary results: Period 2 no consistent DEM of Marinelli Glacier (green circle) – up to now

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Preliminary and general conclusions:

Heterogeneous patterns in Patagonia and Tierra del Fuego glaciers :

NPI: Drastic acceleration of volume loss between 2014-2019
SPI: Similar volume and mass changes in both periods
GCN: Slight increase in ice elevation change and volume loss (2013-2019)
Tierra del Fuego: CD glaciers present a considerable increase in volume change (2013-2019)

volume change rate (Braun et al., 2019 -> 2000-2011/15) of 20.8 $km^3\ a^{-1}$
volume change rate of ~26 $km^3\ a^{-1}$ (2013/2014 -2019)

Next steps:

- Evaluation and intercomparison with ICESAT-2 and GRACE missions
- Detailed revision of AWS in the region

Thank you
Questions and suggestion?. Please do not hesitate to contact the authors (link)

Image: DLR