Short Term Elevation Changes from TanDEM-X for the mass balance of Patagonian glaciers

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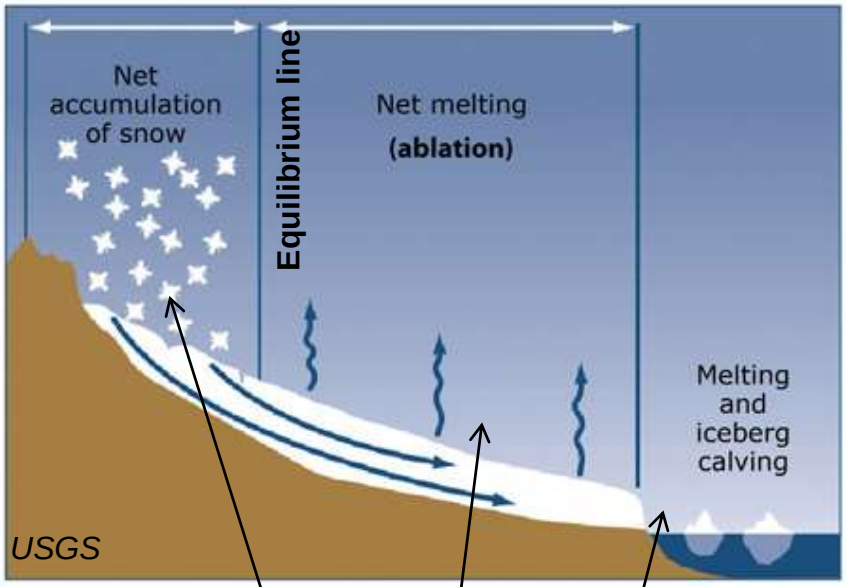
[2]ENVEO IT, Innsbruck, Austria

[3]Universidad de Magallanes, Punta Arenas, Chile



8th EARSeL workshop on Land Ice and Snow, Bern, 7-9 Feb. 2017

Mass balance of glaciers





$$\dot{B} = \dot{B}_{ac} + \dot{B}_{ab} - \dot{B}_{cv}$$

← Input/Output method (IOM)

Surface mass balance Calving loss

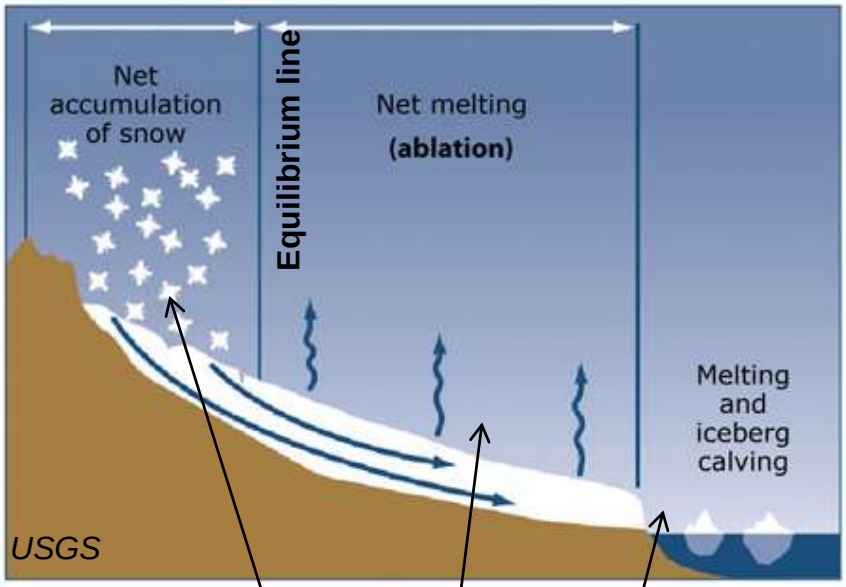
Geodetic mass balance

$$\dot{B} = \rho \int_A \frac{\Delta h}{\Delta t} dA$$

$$\dot{B}_{cv} = \rho \int u_{cv}(y) h(y) dy$$

$\dot{B}$ - (total) glacier mass balance rate

Mass balance of glaciers





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Geodetic mass balance

$$\dot{B} = \rho \int_A \frac{\Delta h}{\Delta t} dA$$

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$\dot{B}$ - total glacier mass balance rate

Southern Patagonia Icefield (SPI)





Lat: **73°30’ W**

Lon: **48°20’ to 51°30’ S**

Area: **13,000 km²**

SRTM - TanDEM-X DEM differencing: (2000-2011/12)

SPI Mass deficit: -13.135 Gt a^{-1}

Southern Patagonia Icefield (SPI)





Lat: **73°30’ W**

Lon: **48°20’ to 51°30’ S**

Area: **13,000 km²**

Glacier basin

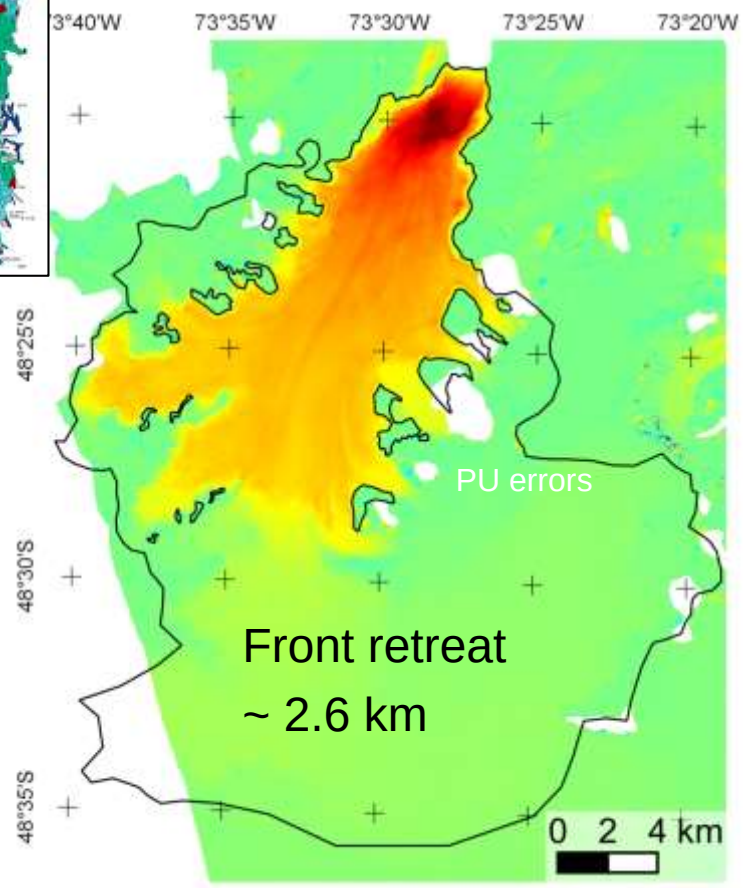
A = 471 km²



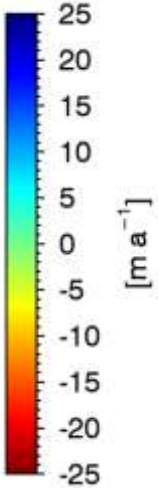
Surface elevation change rate of J.Montt Glacier

9.05.2011 – 02.2000
TanDEM-X - SRTM

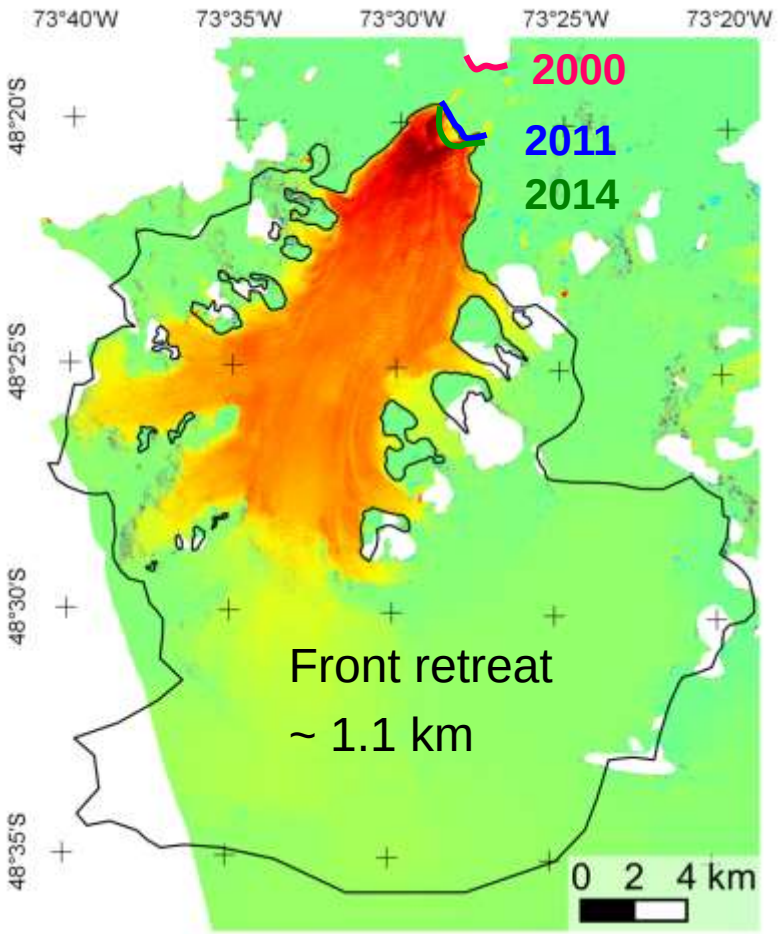




$\frac{\Delta h}{\Delta t}$

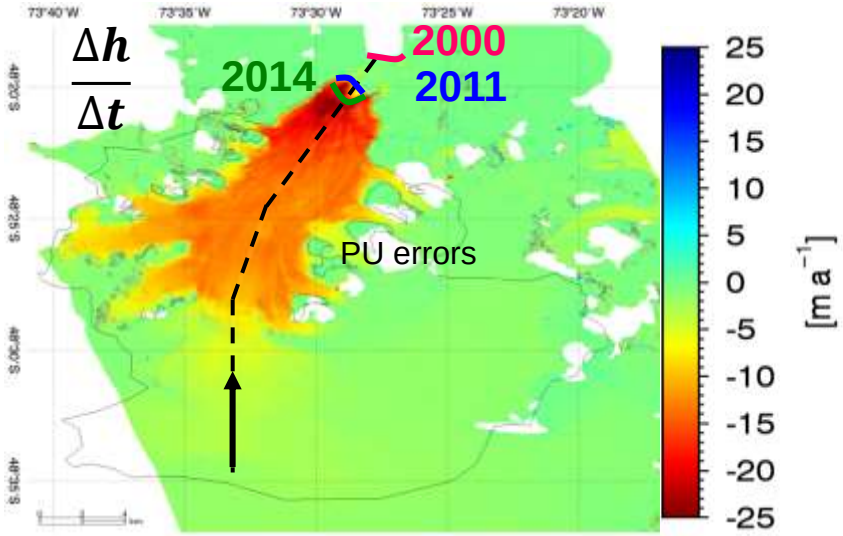


21.04.2014 - 9.05.2011
TanDEM-X DEM difference

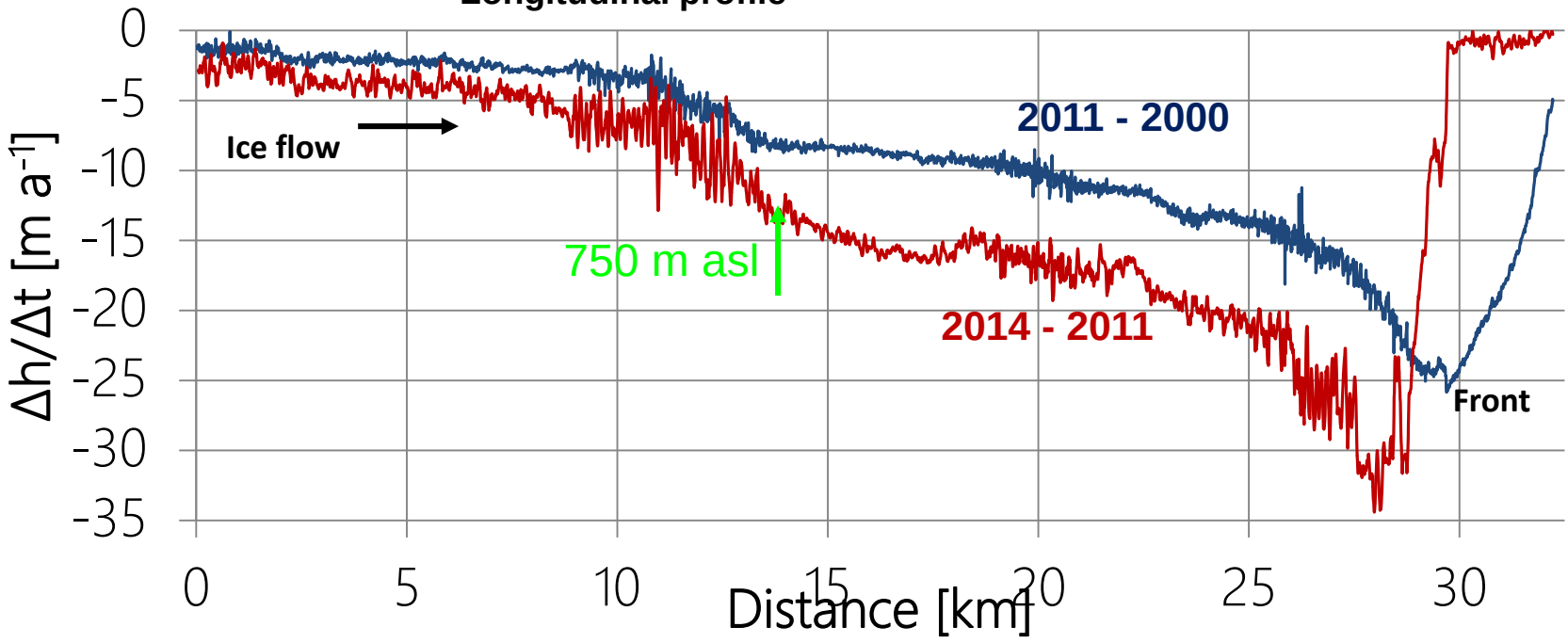


Acceleration of surface lowering J.Montt Glacier 2000 – 2011 vs. 2011 - 2014



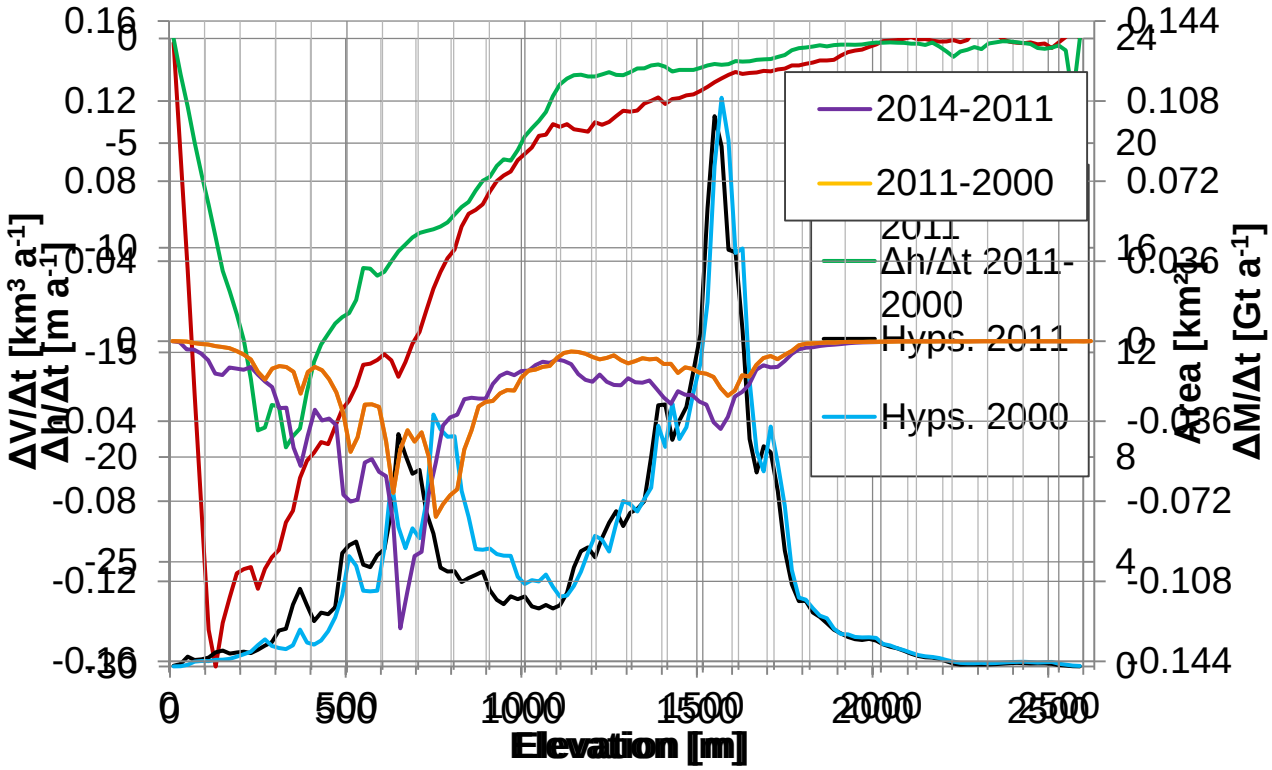


Longitudinal profile



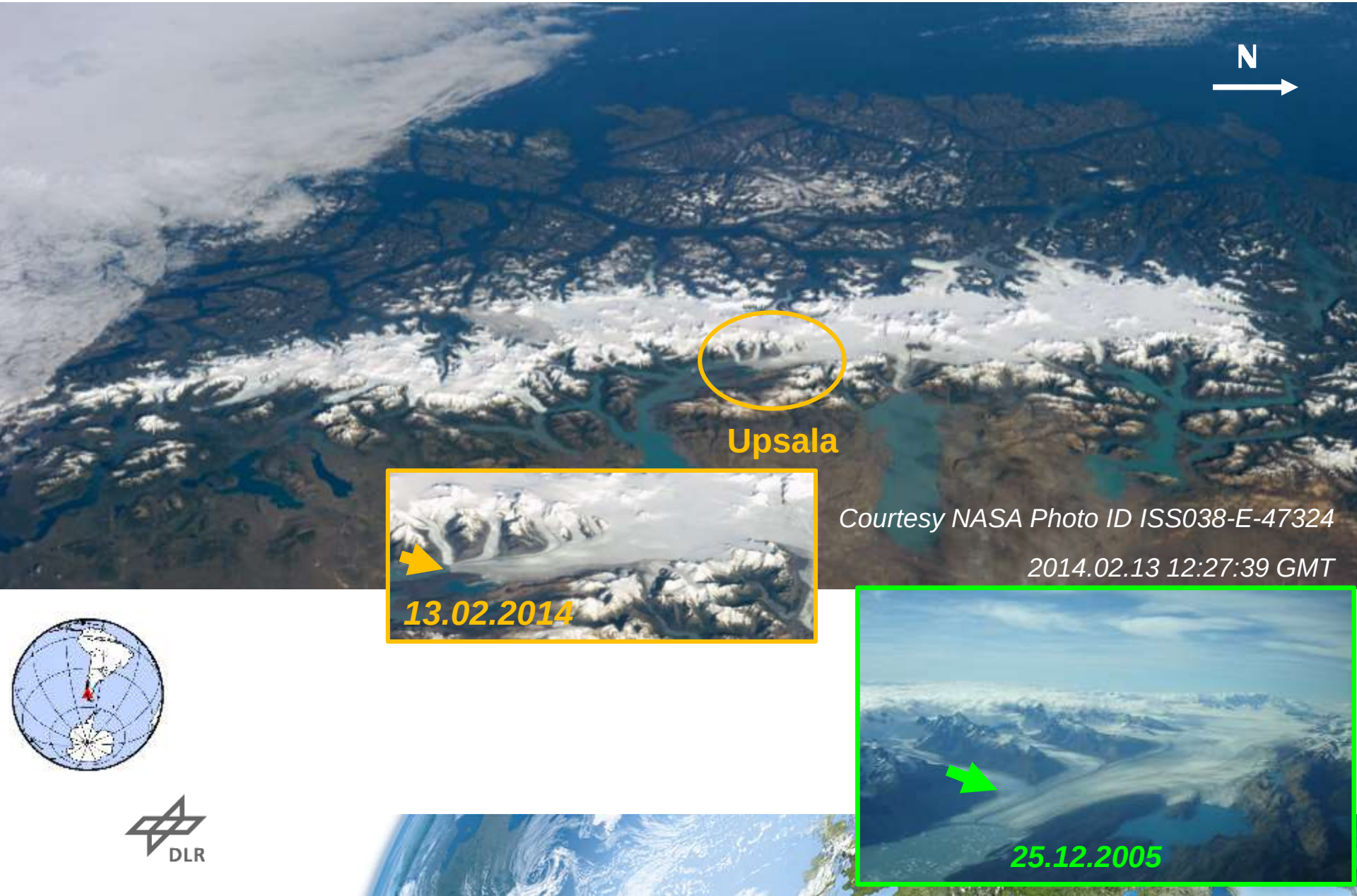
Acceleration of mass depletion of J.Montt Glacier 2000 – 2011 vs. 2011 - 2014



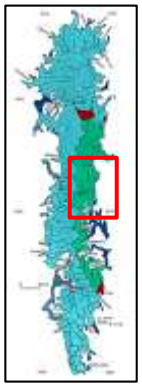


Period	Area [km²]	$\left\langle \frac{\Delta h}{\Delta t} \right\rangle$ [m a^{-1}]*	$\left\langle \frac{\Delta V}{\Delta t} \right\rangle$ [km^{3}a^{-1}]*	$\left\langle \frac{\Delta M}{\Delta t} \right\rangle$ [Gt a^{-1}]*	SLR [μm a^{-1}]
2000 – 2011	489.59	−3.91	−1.91	**−1.72**	4.759
2011 – 2014	470.90	−6.11	−2.88	**−2.59**	7.152

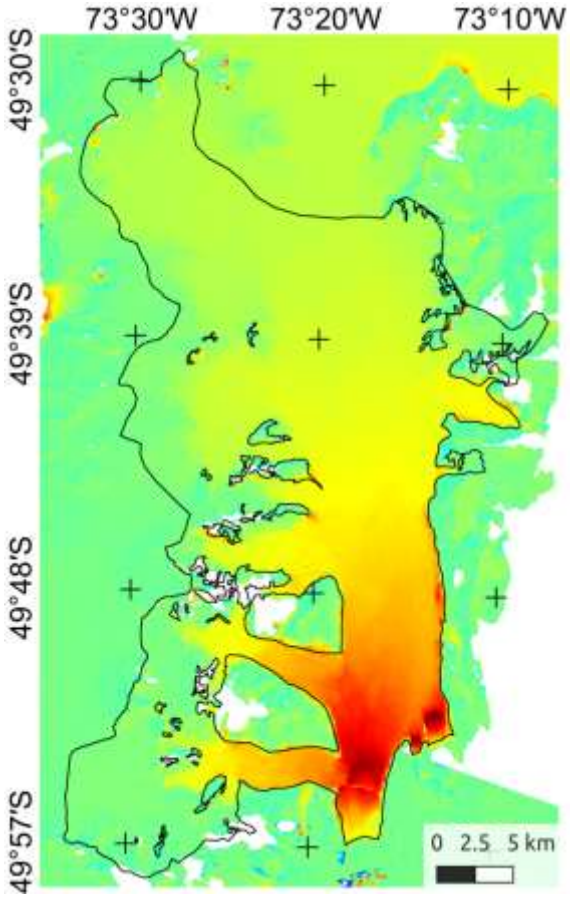
Southern Patagonia Icefield (SPI)



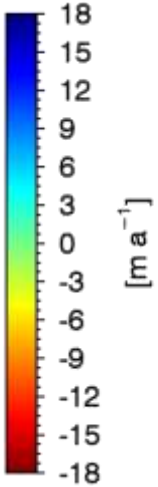
Surface elevation change rate Upsala Glacier



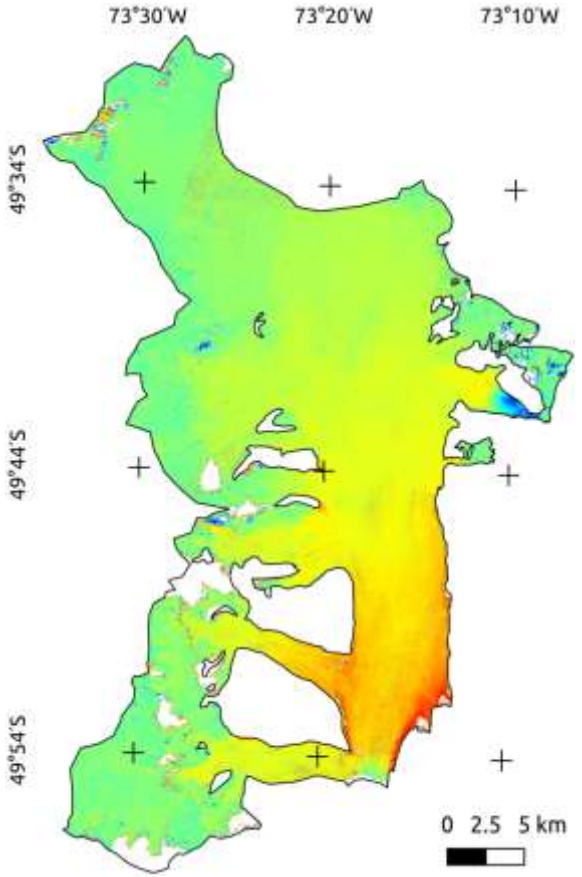
1.05.2011 – 02.2000
TanDEM-X - SRTM



$\frac{\Delta h}{\Delta t}$



8.02.2013 - 1.05.2011
TanDEM-X DEM difference



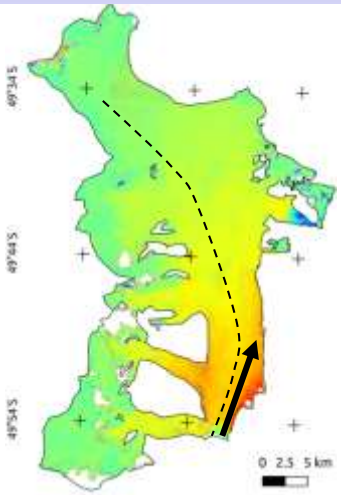
Front retreat ~ 3.5 km

Surface loss ~ 9.8 km^2

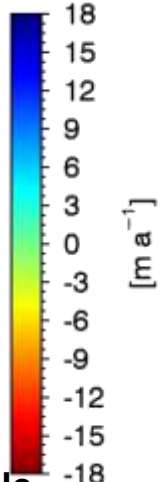
Front retreat ~ 0.5 km

Surface elevation change rate Upsala Glacier

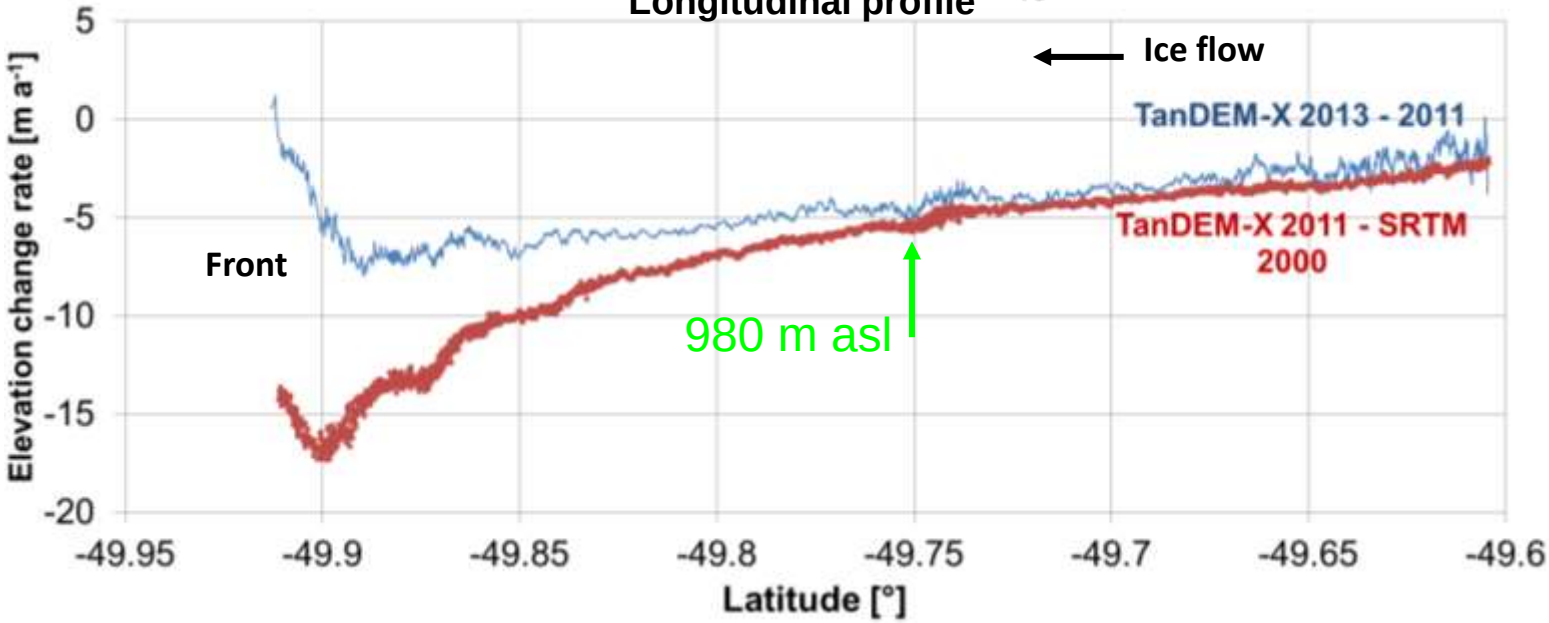




$$\frac{\Delta h}{\Delta t}$$

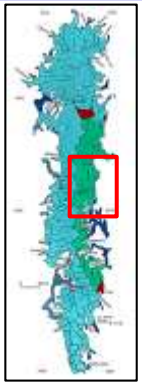


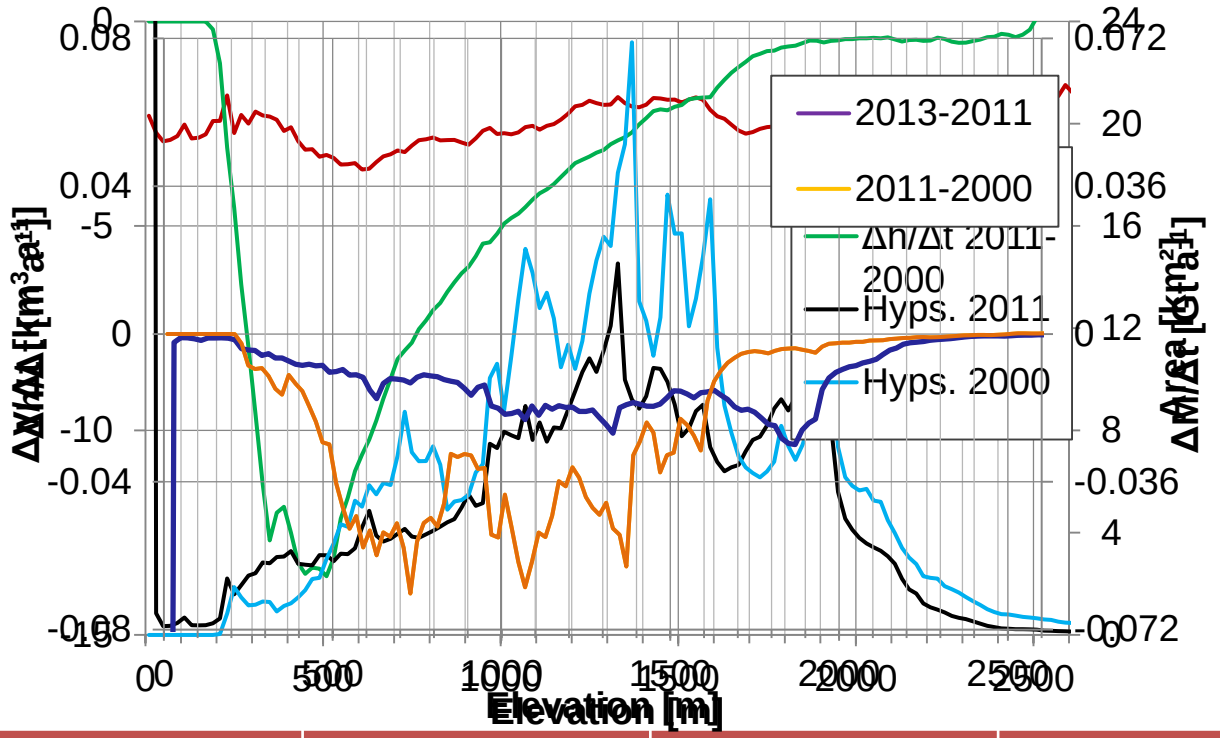
Longitudinal profile



DLR

Acceleration of mass depletion of Upsala Glacier 2000 – 2011 vs. 2011 - 2013





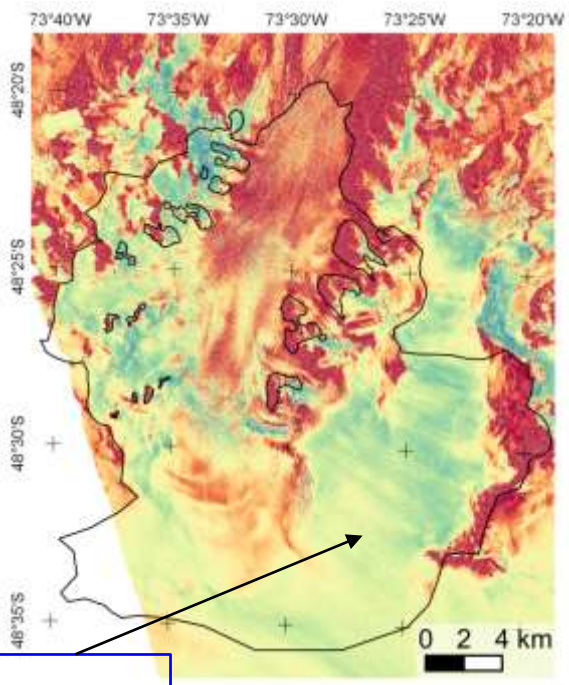
Period	Area [km²]	$\left\langle \frac{\Delta h}{\Delta t} \right\rangle$ [m a^{-1}]*	$\left\langle \frac{\Delta V}{\Delta t} \right\rangle$ [km^{3}a^{-1}]*	$\left\langle \frac{\Delta M}{\Delta t} \right\rangle$ [Gt a^{-1}]*	SLR [µm a^{-1}]
2000 – 2011	837.0	−3.49	−2.85	**−2.56**	7.072
2011 – 2013	827.7	−2.45	−2.03	**−1.83**	5.055

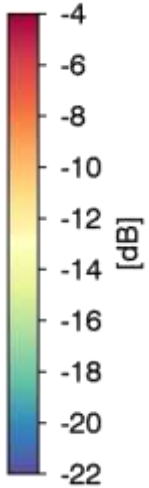
Radar signal penetration: TanDEM-X backscattering analysis

TanDEM-X: β^0

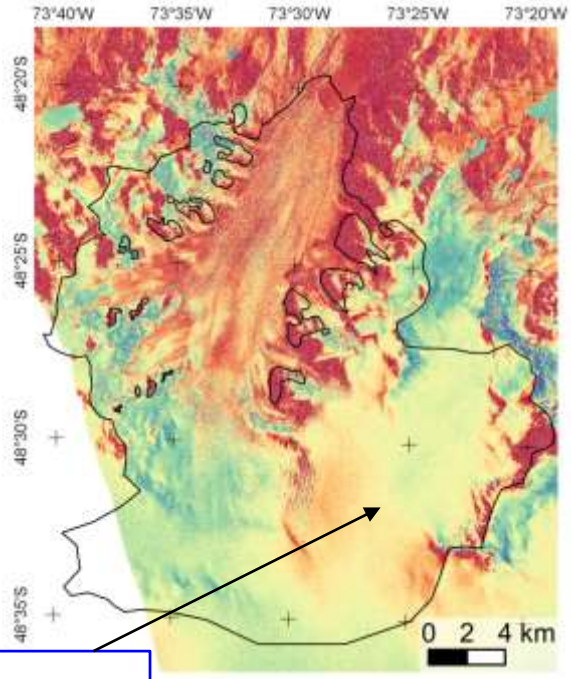
θ_i=34deg

9.05.2011





21.04.2014



$\overline{\sigma^0}$ = -17.6 dB

Wet snow

$\overline{\sigma^0}$ = -17.5 dB

Wet snow

$\sigma^0 = \beta^0 \sin\theta_i$

Radiometric accuracy: 0.3 dB (rel)/ 0.6 dB (abs)

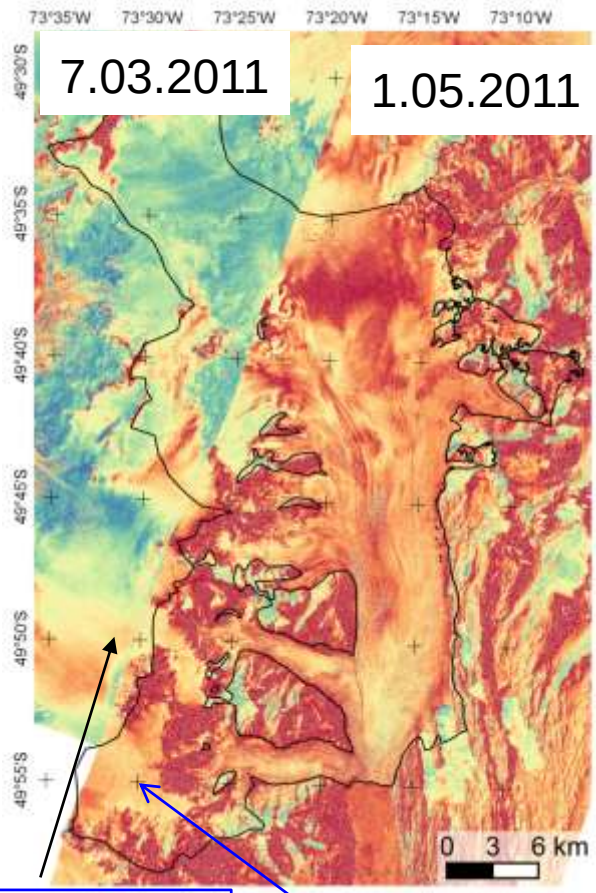
NESZ accounted: [-17; -28] dB

θ_i=34deg

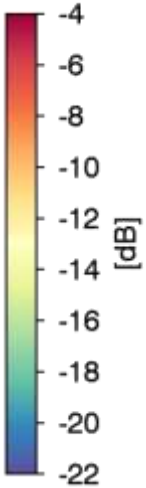
Termini

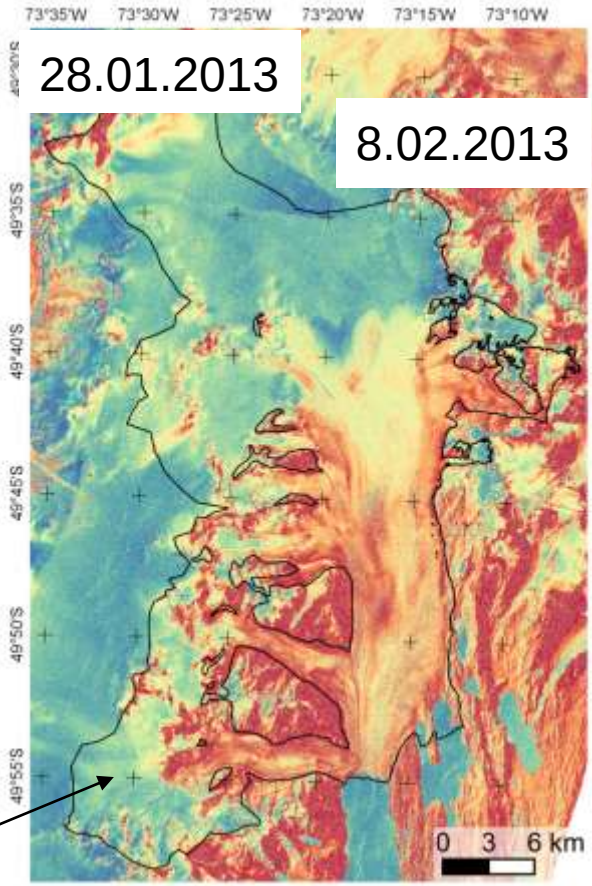
$\overline{\sigma^0}$ > -13 dB Rough surface

Radar signal penetration: TanDEM-X backscattering analysis



β^0





$\overline{\sigma^0}$ = -14.6 dB
Wet snow 20110307

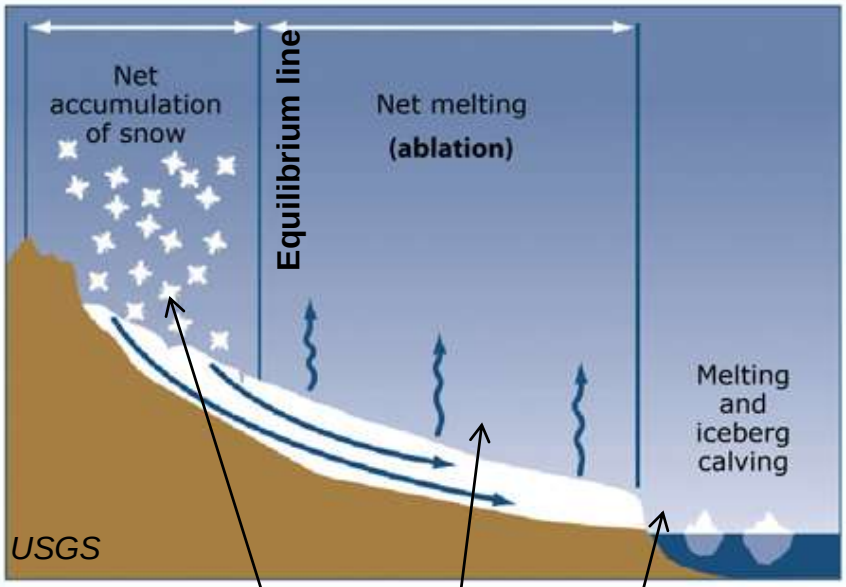
$\overline{\sigma^0}$ = -11.7 dB
20110501

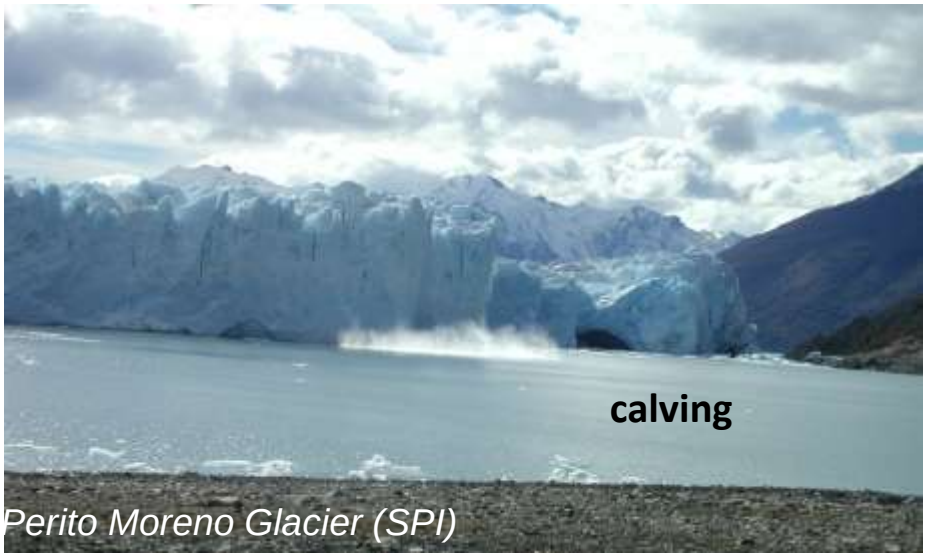
$\overline{\sigma^0}$ = -13.1 dB
20110501

$\overline{\sigma^0}$ = -15.8 dB
wet snow 20110307

$\overline{\sigma^0}$ = -20 dB
wet snow

Mass balance of glaciers





$$\dot{B} = \dot{B}_{ac} + \dot{B}_{ab} - \dot{B}_{cv}$$

Surface mass balance Calving loss

← Glacier mass balance rate $\dot{B}$

$$\dot{B} = \rho \int_A \frac{\Delta h}{\Delta t} dA$$

$$\dot{B}_{cv} = \rho \int u_{cv}(y) h(y) dy$$

y – coord. parallel to glacier front

u_{cv} – calving rate; h – ice thickness

Estimation of mass loss by calving

$$\dot{B}_{cv} = \rho \int u_{cv}(y) h(y) dy$$

y – coord. parallel to glacier front

h – ice thickness

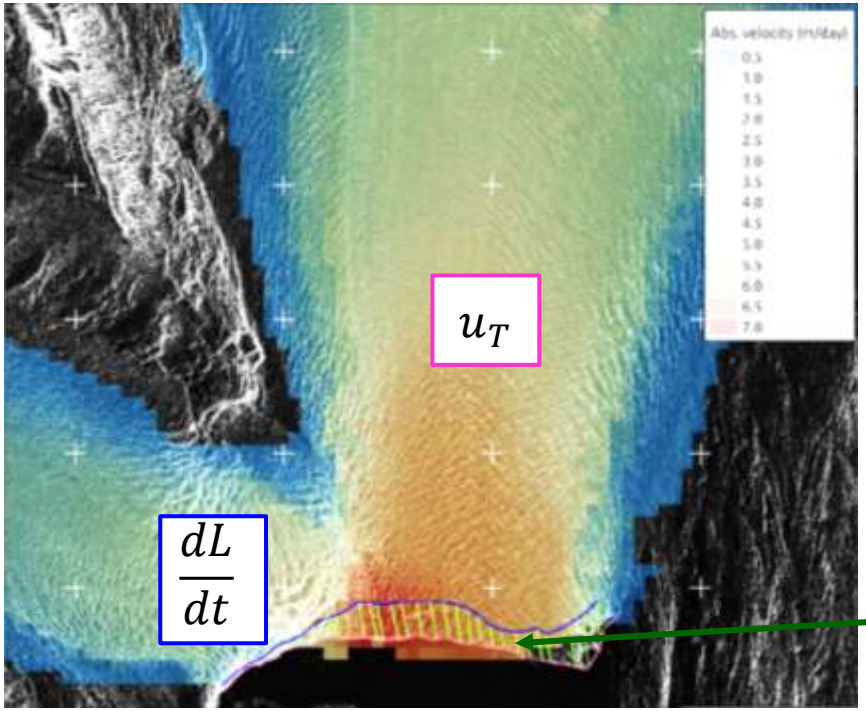
- calving velocity : $u_{cv} = u_T - \frac{dL}{dt}$ ⊥ to the flux gate (calving front)

u_T - the velocity at the terminus on every flow line

$\frac{dL}{dt}$ - length change rate of the terminus

u_T: pair
14.08/25.08.2013
(126D_s012)

$\frac{dL}{dt}$:
frontal positions
14.08.2013 (126D_s12)
&
25.08.2014 (165A_s13)



Estimation of mass loss by calving

$$\dot{B}_{cv} = \rho \int u_{cv}(y) h(y) dy$$

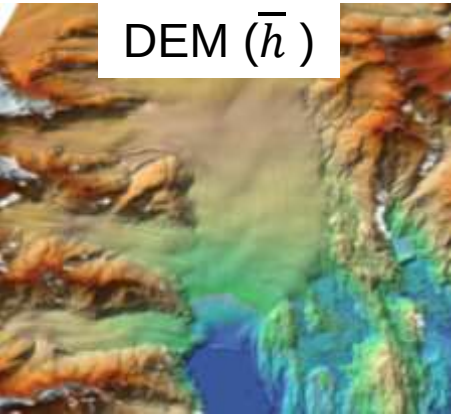
y – coord. parallel to glacier front

h – ice thickness

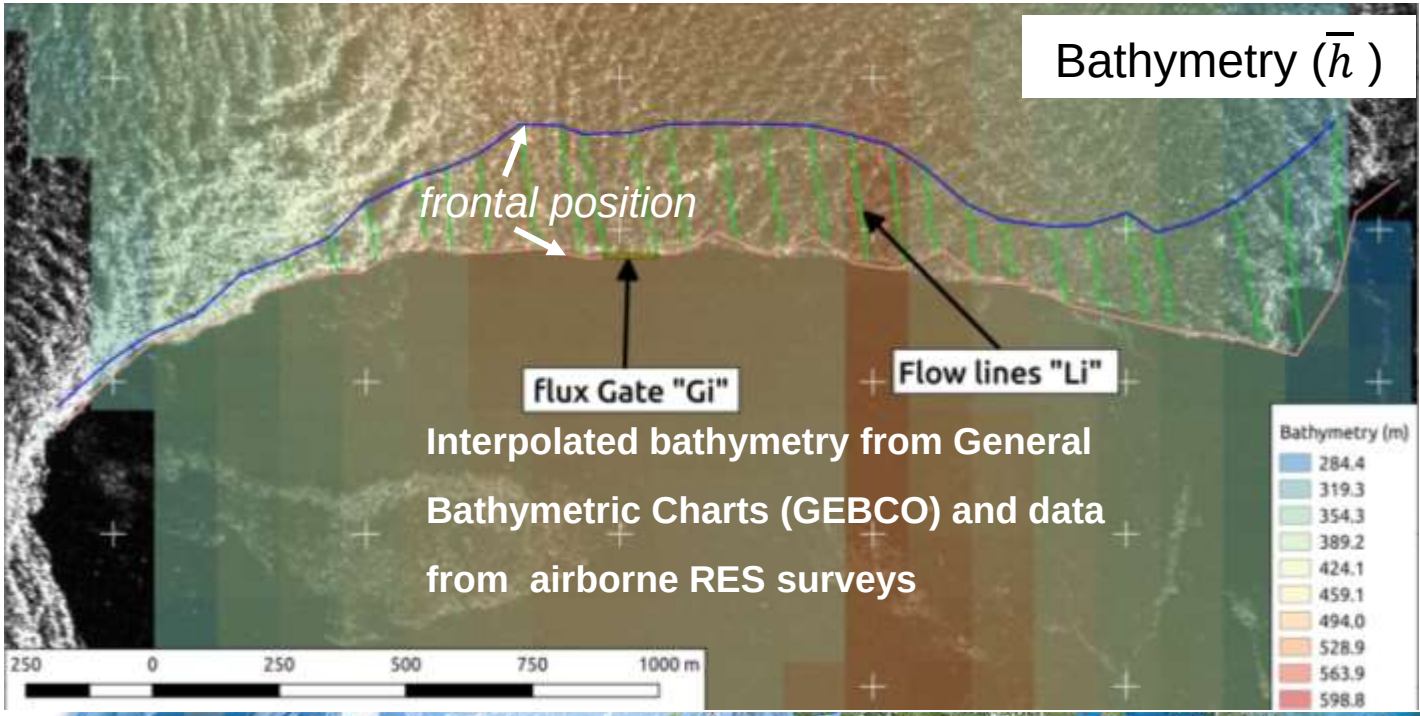
- calving flux: $Q_c = \overline{h} \cdot \overline{w} \cdot u_{cv}$

$\overline{h}$ - ice thickness; $\overline{w}$ - frontal glacier width

DEM ($\overline{h}$)



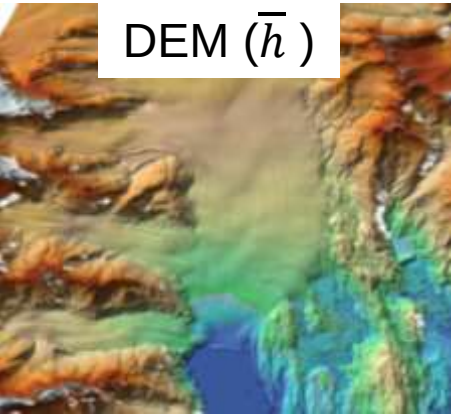
Bathymetry ($\overline{h}$)

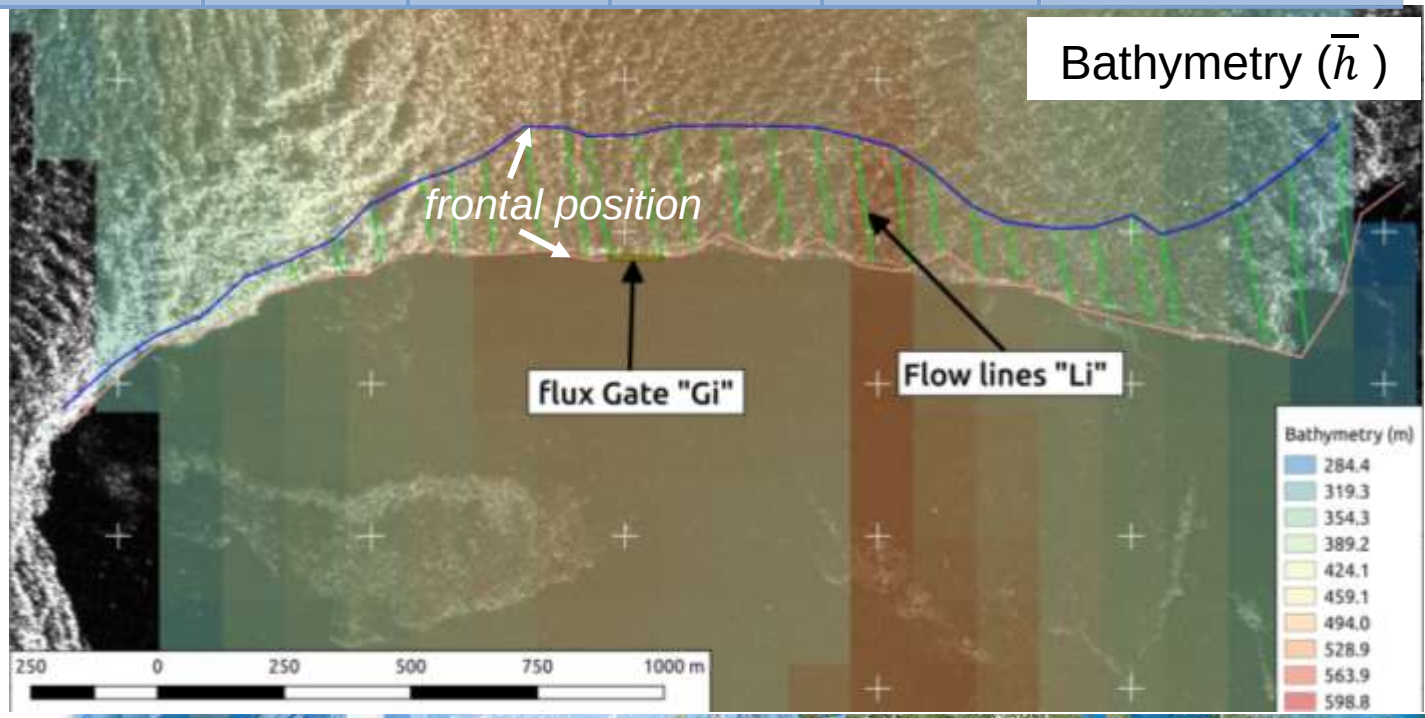


Estimation of mass loss by calving

Upsala Glacier: 14.08.2013 – 25.08.2014

G1 (km^3/y)	G2 (km^3/y)	G3 (km^3/y)	G4 (km^3/y)	G5 (km^3/y)	G6 (km^3/y)	G7 (km^3/y)	G8 (km^3/y)	G9 (km^3/y)
0.018377	0.034449	0.031942	0.041880	0.058162	0.050225	0.032826	0.023948	0.041245
G10 (km^3/y)	**G11 (km^3/y)**	**G12 (km^3/y)**	**G13 (km^3/y)**	**G14 (km^3/y)**	**G15 (km^3/y)**	**G16 (km^3/y)**	**G17 (km^3/y)**	**G18 (km^3/y)**
0.036734	0.057629	0.059350	0.058451	0.070376	0.047512	0.030203	0.033775	0.042477
G19 (km^3/y)	**G20 (km^3/y)**	**G21 (km^3/y)**	**G22 (km^3/y)**	**G23 (km^3/y)**	**G24 (km^3/y)**	**G25 (km^3/y)**	**TOTAL (km^3/y)**	
0.069845	0.040633	0.039705	0.039593	0.071402	0.021346	0.022921	1.07501	





Conclusions

- High horizontal and vertical resolution topographic data provided by TanDEM-X are sensitive to short term variations of surface elevation.

- On the outlet glaciers of the Southern Patagonia Icefield the ongoing decrease in the elevation at the ice surface reveals a strong mass depletion.

  J. Montt Gl.: the mass loss in the time range 2011-2014 increases compared to 2000 - 2011

  Upsala Gl: the spatial pattern of the thinning changes

  → Glacier volume change needs measurements at short time scales.

  → Individual components of the mass balance is required for the link glacier behaviour – climate and dynamic response of glaciers

  → Numerical modeled surface mass balance of glaciers in Patagonia from regional scale RACMO model will be validated through the geodetic mass balance & the calving flux derived from remote sensing data.

Thank you for your attention!

SAMBA - ***S****AR* ***A****lgorithms for* ***M****ass* ***BA****lance and Dynamics of Calving Glaciers*

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