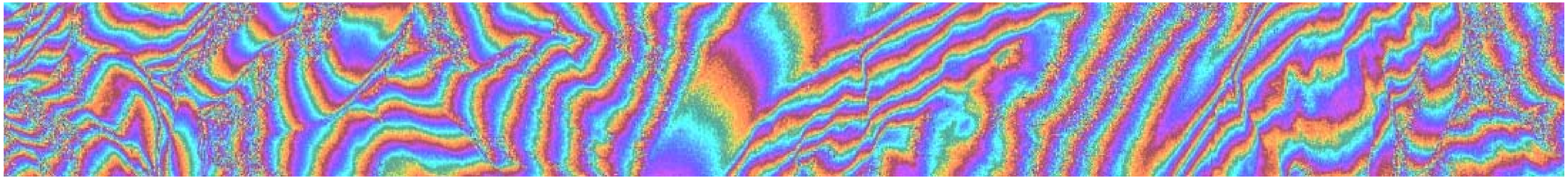

Observing Volume Changes and Mass Balance of Glaciers by Means of TanDEM-X and TerraSAR-X Data

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Outline of the Presentation

- SAR application to retrieval of glacier mass balance
- SAR signal penetration in snow and ice
- Topographic changes of Ötztal glaciers
- Mass balance estimate and comparison with in situ data
- Analysis of TerraSAR-X and TanDEM-X data for estimating calving fluxes of Antarctic Peninsula glaciers
- Mass balance of outlet glaciers on the northern Larsen Ice Shelf coast
- Conclusions

TerraSAR-X and TanDEM-X data were supplied through the projects XTI_GLAC0457, XTI_GLAC0331, HYD0396

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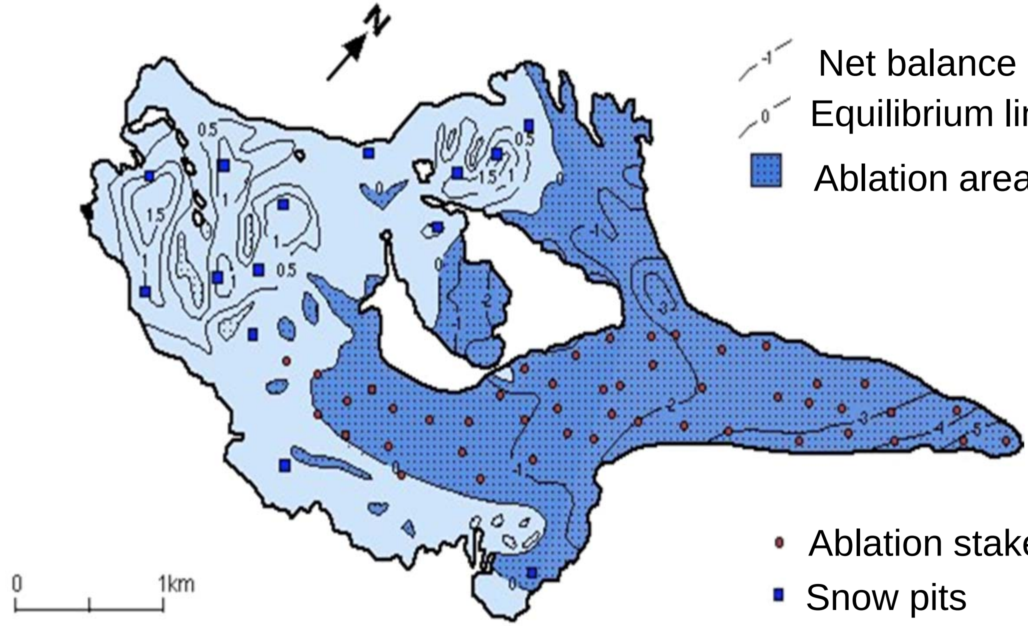
SAR Application to Glacier Mass Balance

Field survey of mass balance



Net balance B_n
Equilibrium line
Ablation area

Ablation stakes
Snow pits

Net mass balance: $B_N = B_{AC} + B_{AB}$

Accumulation *Ablation*

Typical time interval for measurement of B_N: 1 year

Geodetic method for mass balance:

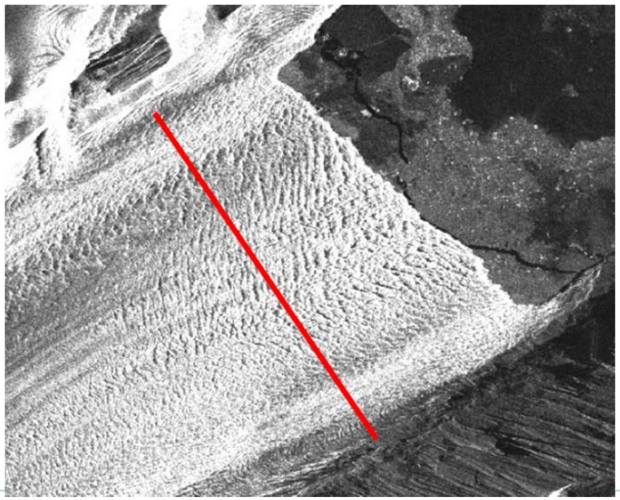
$$B_N = \sum_{i=1}^{A} \Delta z(i) \rho(i)$$

Calving Glaciers $B_N = B_{AC} + B_{AB} + B_C$

Calving Flux $$B_c = \rho_i \int_Y \left[\overline{u}(y) H(y)\right] dy$$

Calving Velocity by SAR repeat pass

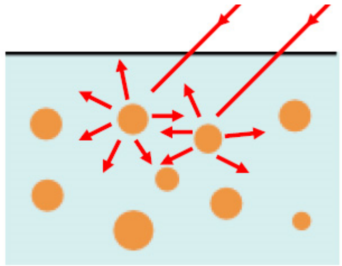
Ice Thickness by InSAR DEM at floating gate

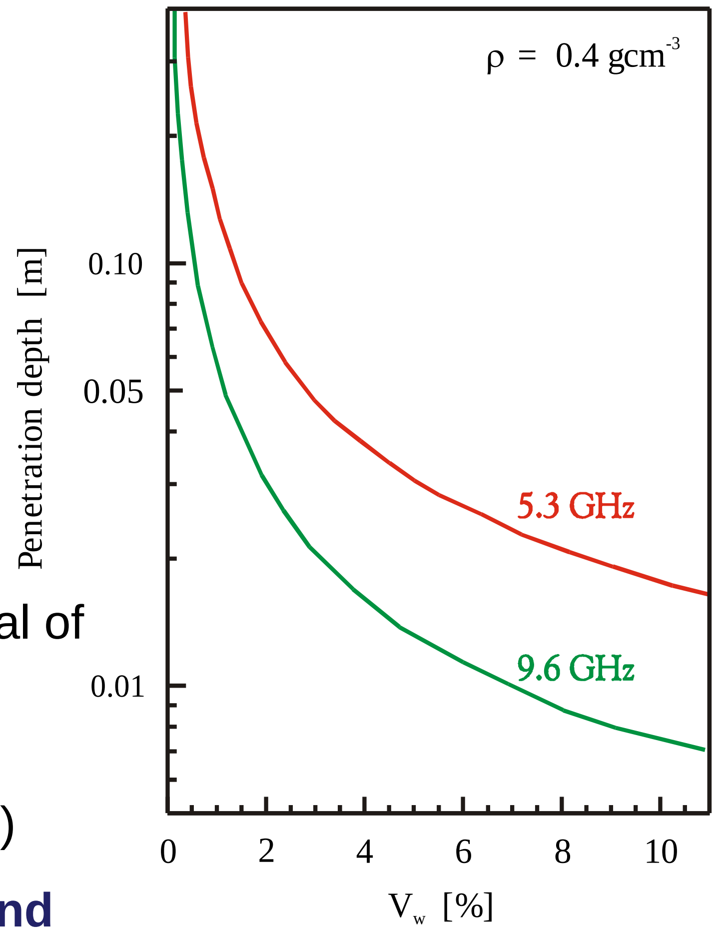


InSAR – DEM: Apparent Location of Surface

The interferometric elevation refers to the **position of the scattering phase center** in snow and ice (in **dry snow up to several meters below surface**)

Its depth below the surface depends on
• SAR wavelength
• Liquid water content of snow volume
• Scattering properties of volume and surface





Liquid water

Options for compensating penetration for retrieval of elevation change:

- Use repeat observations at **same radar frequency and snow state** (either dry or wet)
- Estimate penetration **for given snow state and radar frequency** (using model and/or empirical data)

InSAR Date Base for Mass Balance of Ötztal Glaciers

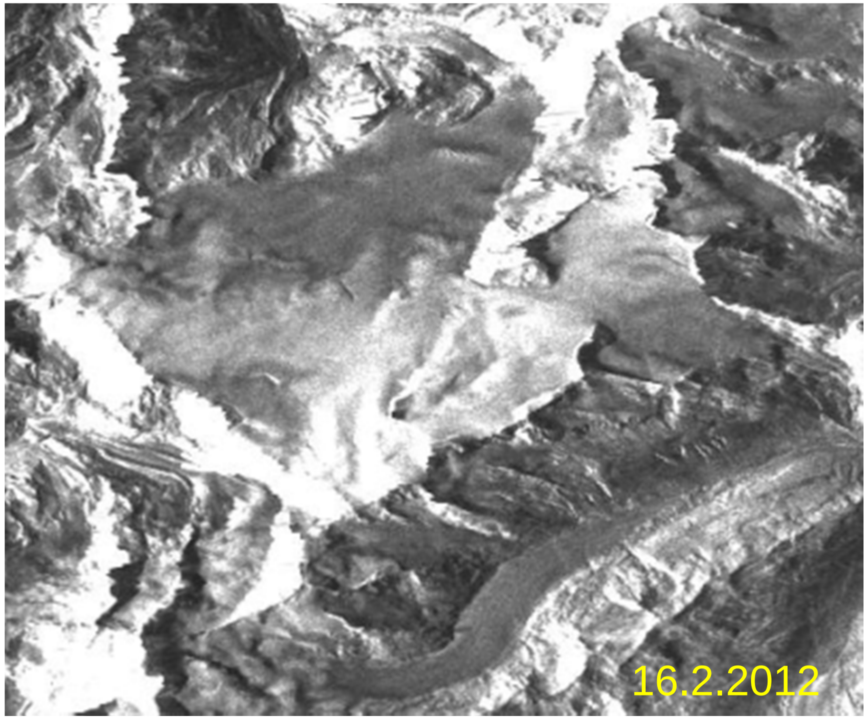
Data Base: SRTM C-Band, February 2000

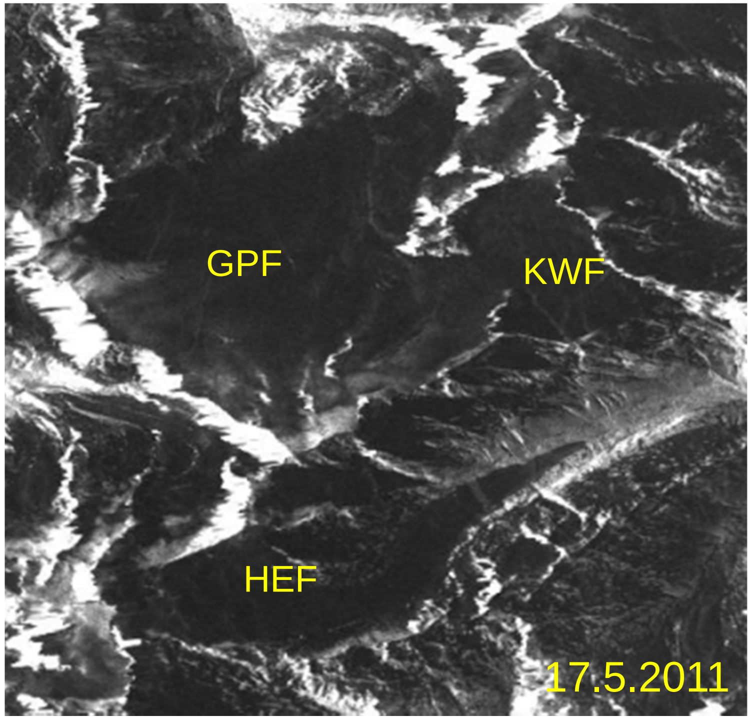
TanDEM-X 17.5.2011 ca. 17 h UTC (ascending orbit)

- Baseline B_n = 158 m H_a = 45.2 m
- Wet snow surface (no penetration), low backscatter

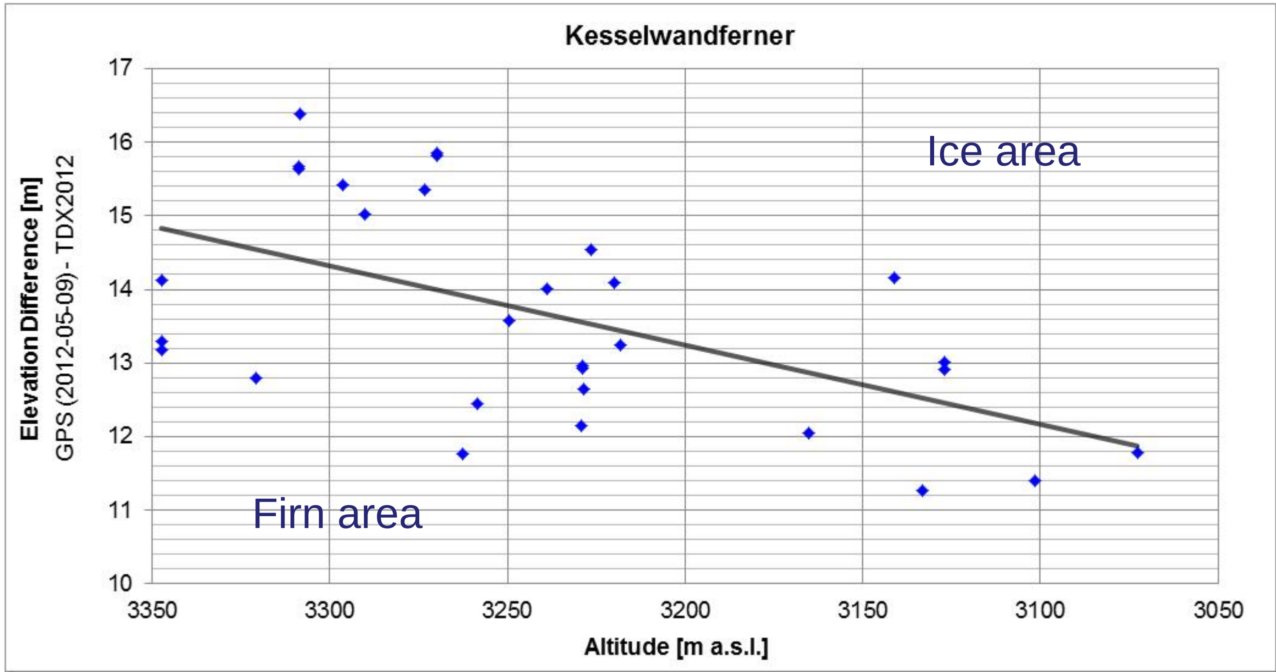
TanDEM-X 16.2.2012 ca. 17 h UTC (ascending orbit)

- Baseline B_n = 86.2 m H_a = 84.0 m
- High radar reflectivity (dry snow)

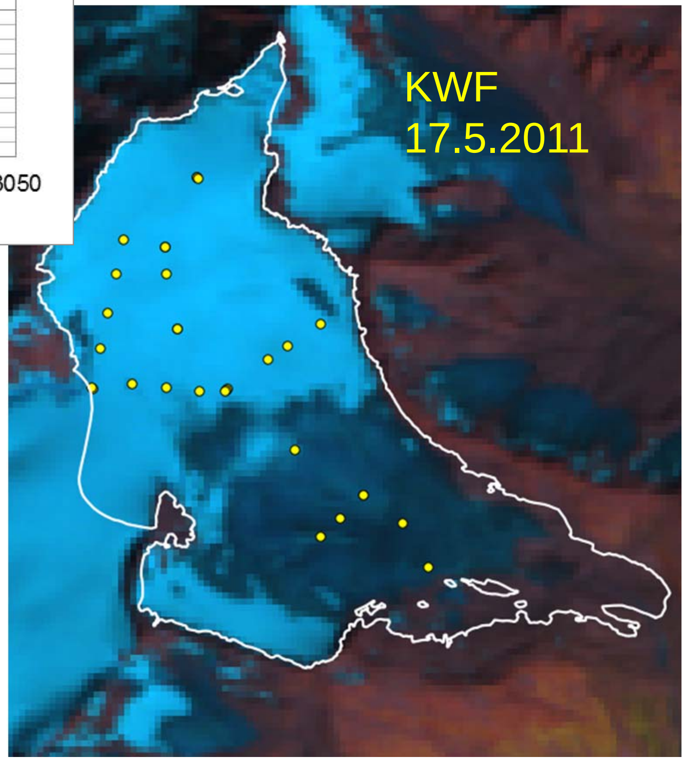




Elevation Difference to GPS – InSAR DEM



Systematic difference in z between InSAR DEM and GPS due to difference in penetration ice / firn

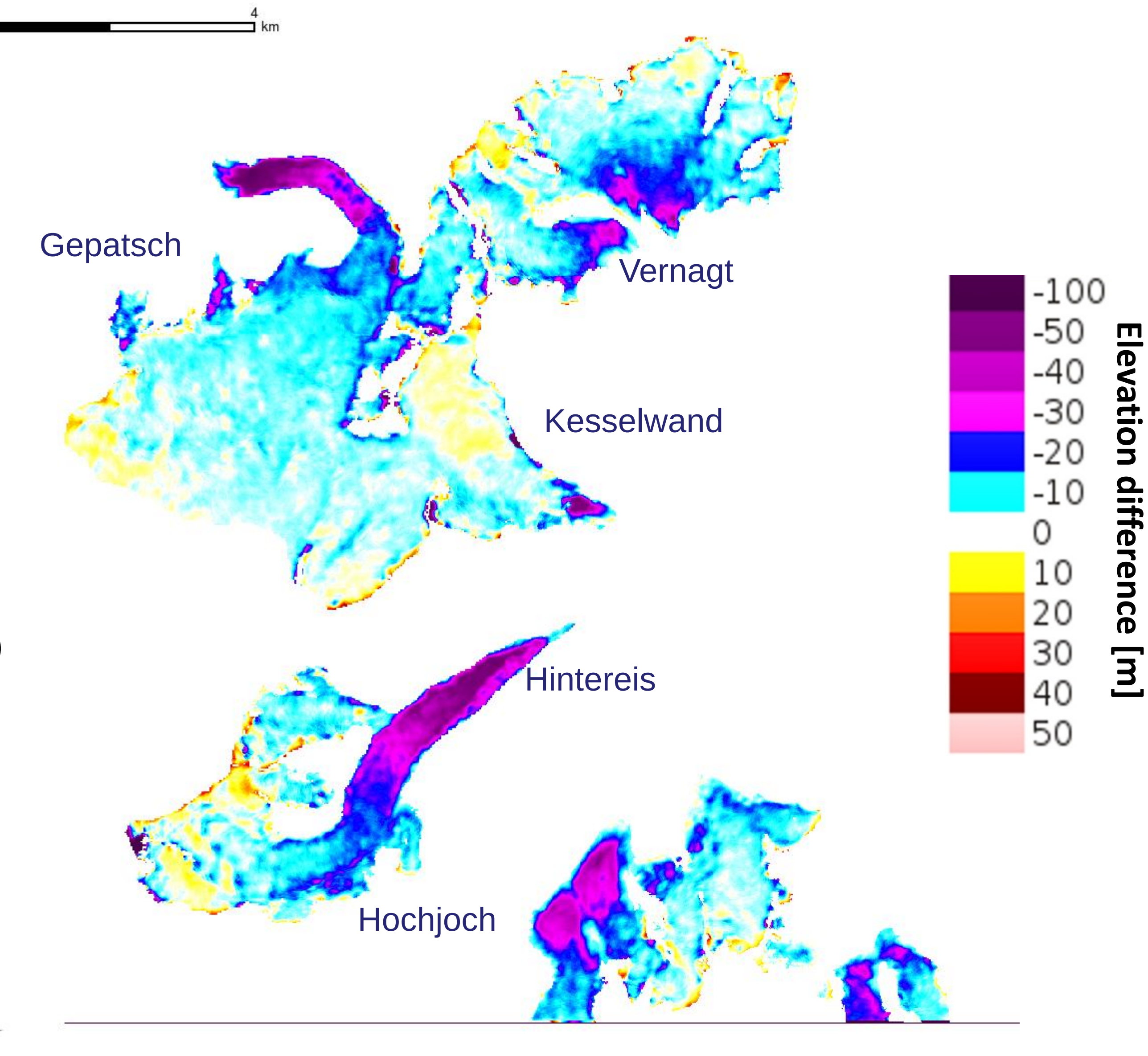


TanDEM-X DEM: 16 Feb 2012 (dry winter snow above frozen firn and ice)

GPS elevation refers to snow surface, 9 May 2012

Difference between the geodetic reference systems not yet compensated

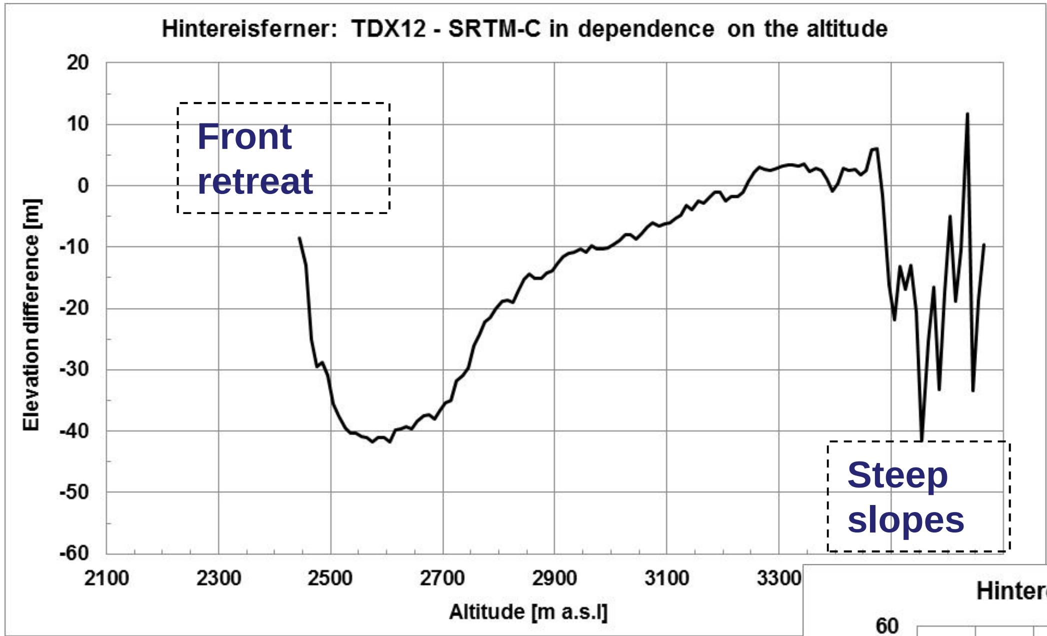
Elevation Change TanDEMX - SRTM



TanDEM-X 16.2.2012

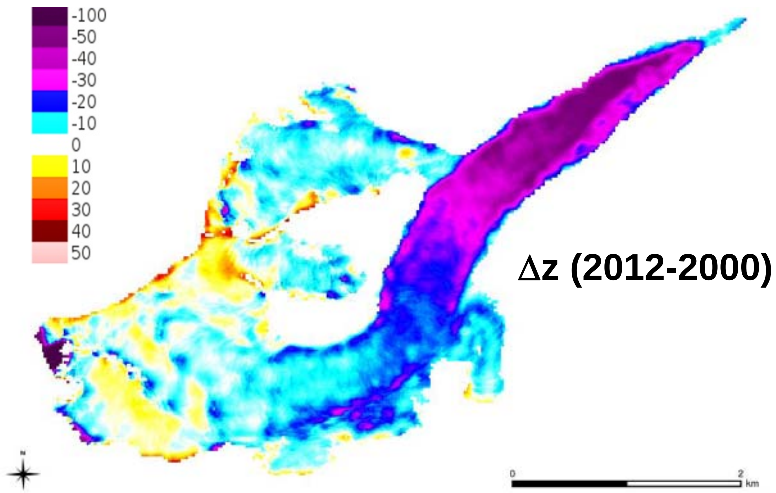
SRTM Feb 2000

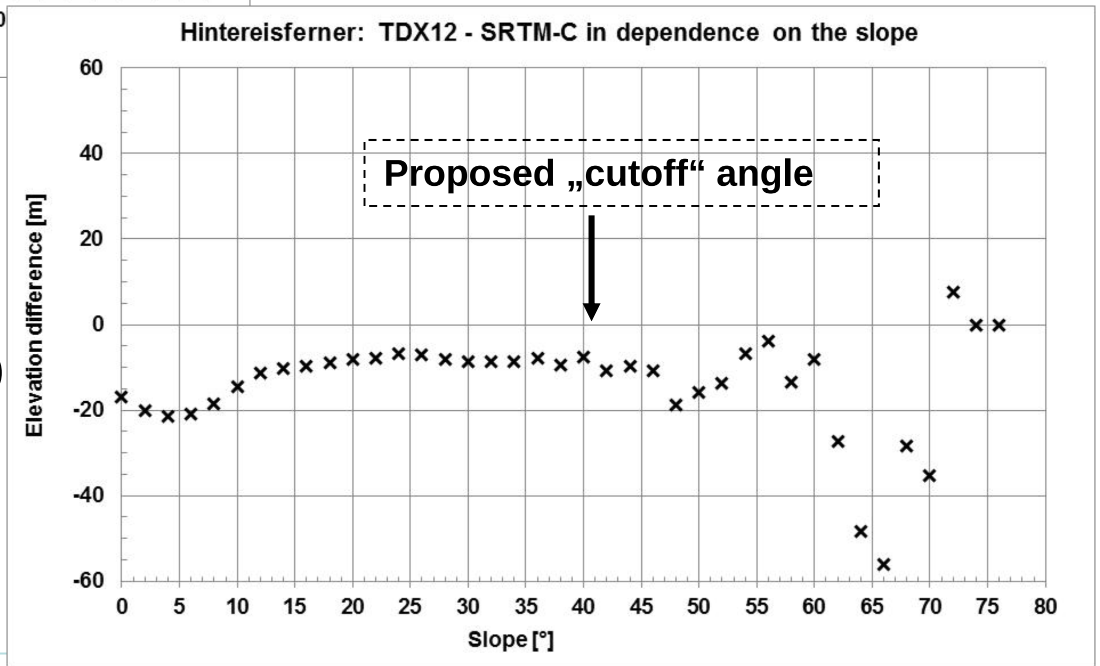
Impact of DEM Grid Size and Surface Slope



Δz TDX-2012 – SRTM-C

Large DEM grid size (SRTM-C, 90 m) causes uncertainty of z on steep slopes

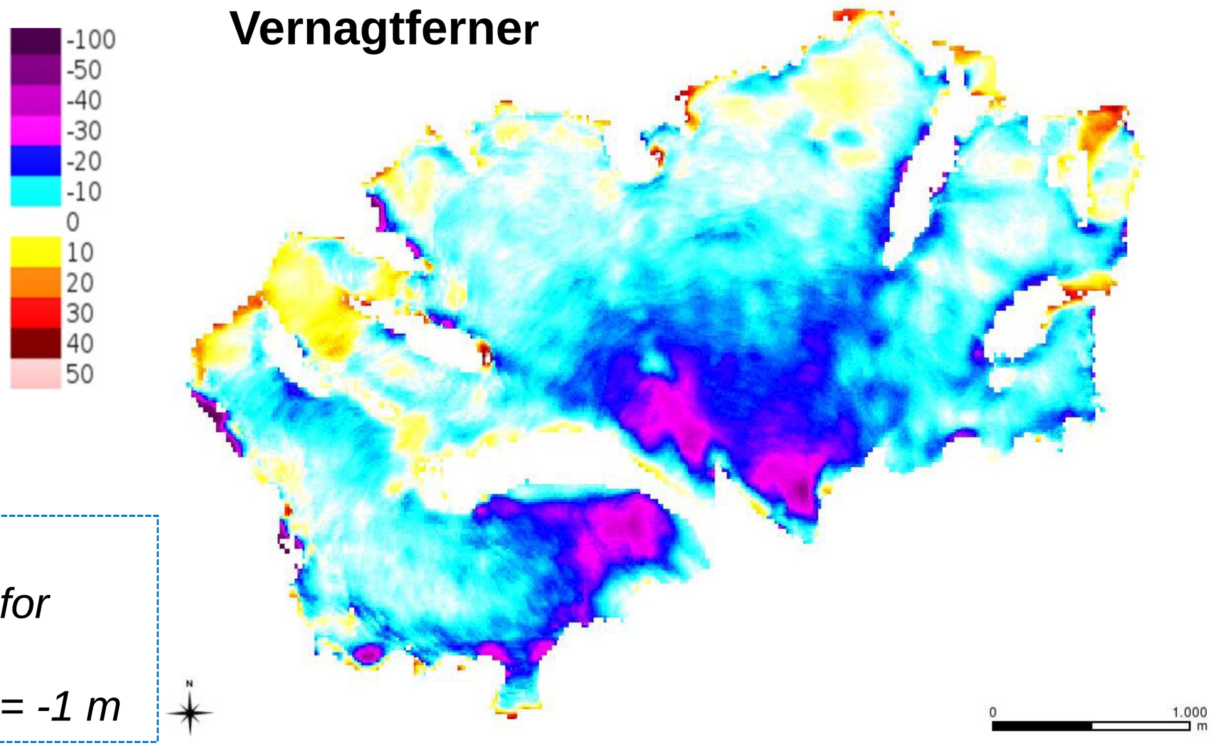




Mass Balance Comparison InSAR ΔV vs. in Situ

Vernagtferner

Δz (2012-2000)



C-band – X-band
Applied correction for penetration (mean Δz (SRTM – TDX) = -1 m

Comparision with in situ mass balance measurements

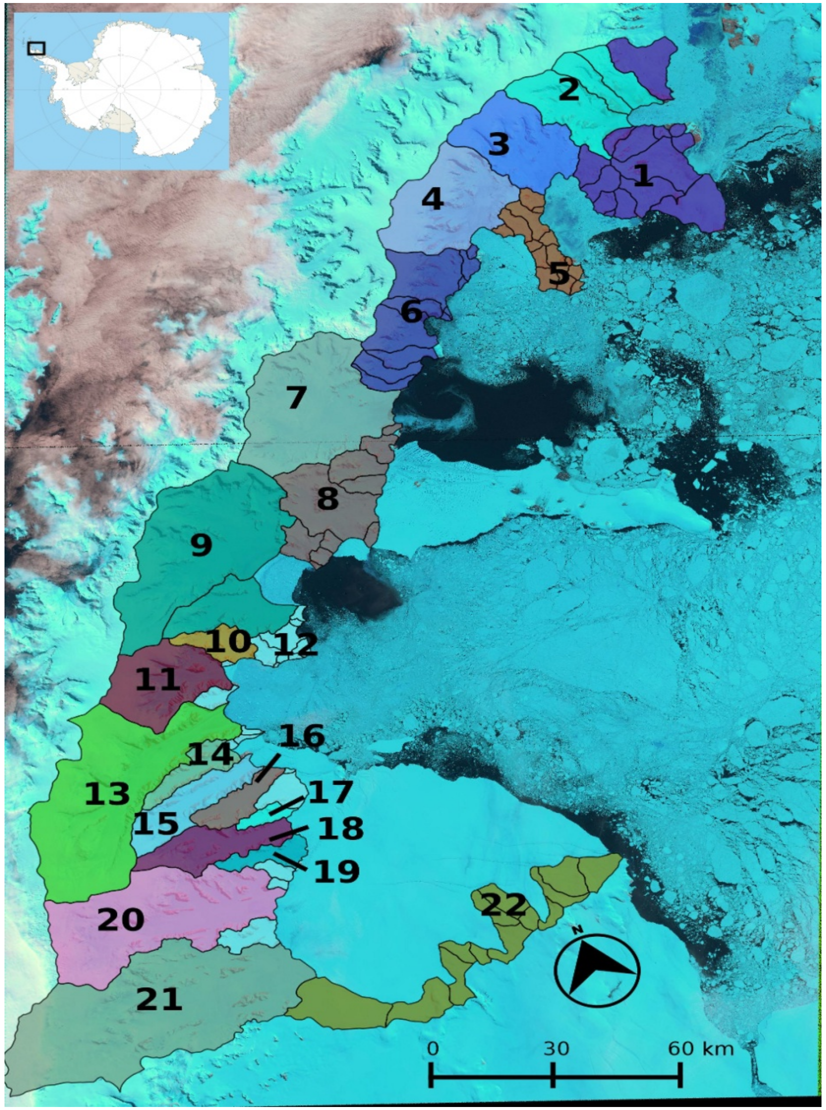
Hintereisferner: $\Delta V = -108.3 \times 10^6\ m^3$ $\Delta M = -93.4 \times 10^6\ m^3$ ($\rho = 900\ kg\ m^{-3}$)

in situ MB 1999/00 to 2011/12: $\Delta M = -95.4 \times 10^6\ m^3$

Vernagtferner: $\Delta V = -98.3 \times 10^6\ m^3$ $\Delta M = -79.5 \times 10^6\ m^3$

in situ MB 1999/00 to 2011/12: $\Delta M = -75.6 \times 10^6\ m^3$

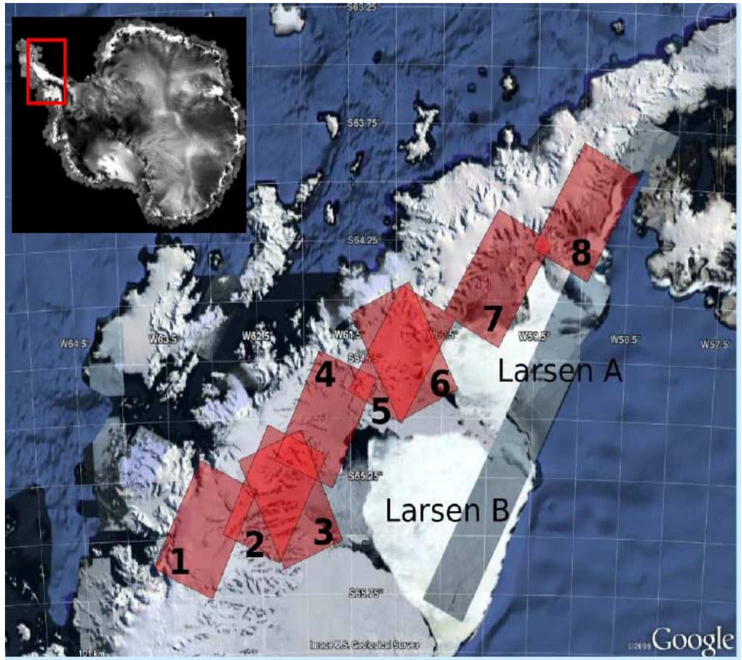
Volume Change and Mass Depletion of Outlet Glaciers on Larsen Ice Shelf Coast



Drainage Basins of Glaciers along Weddell Coast

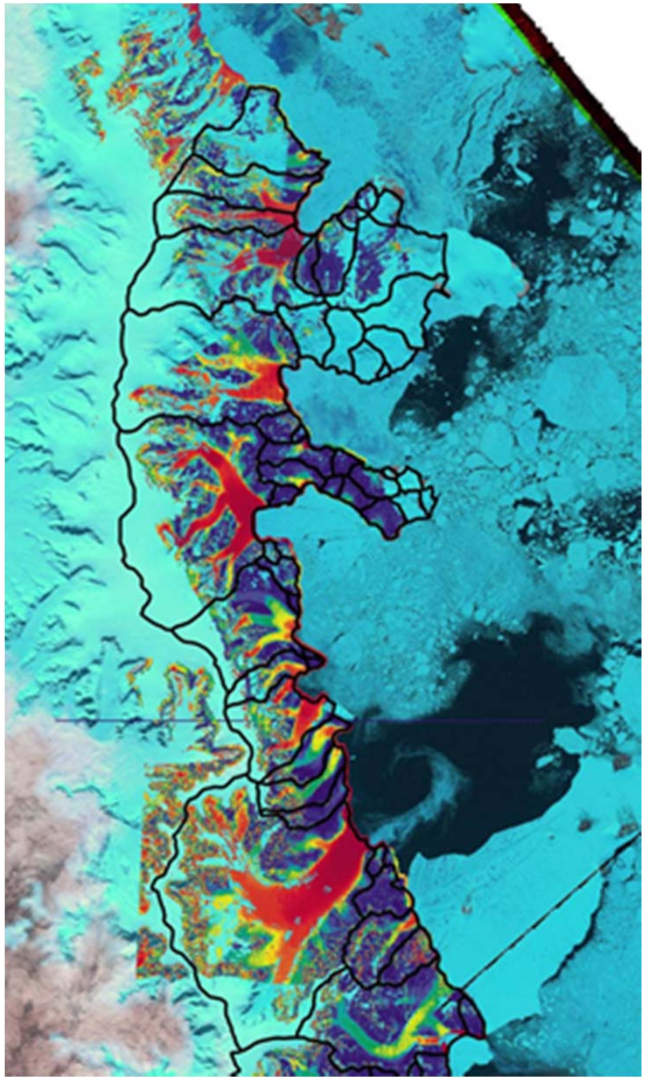
Prince-Gustav-Channel
Larsen-A
Larsen-B

Data Base
TerraSAR-X and TanDEM-X

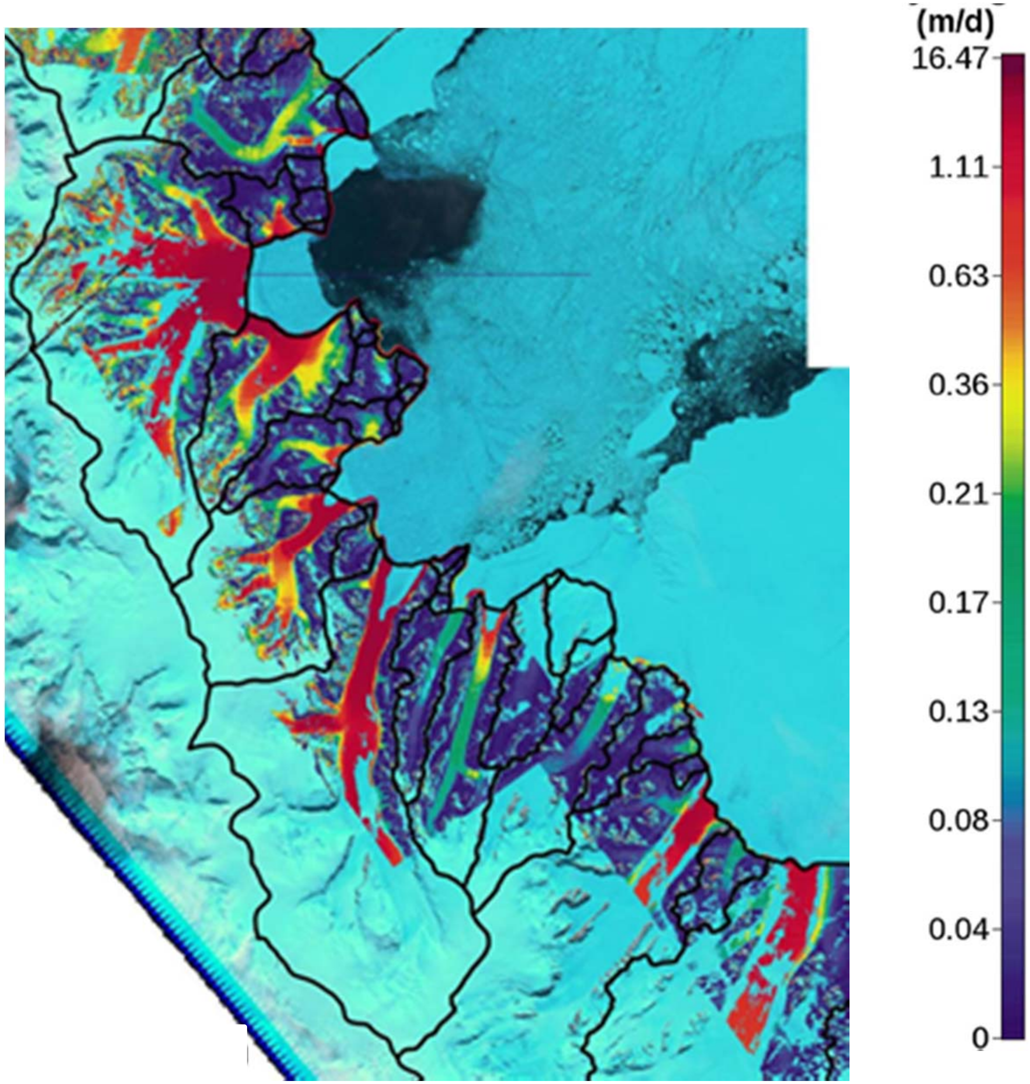


TerraSAR-X Ice Motion Maps of Larsen Coast

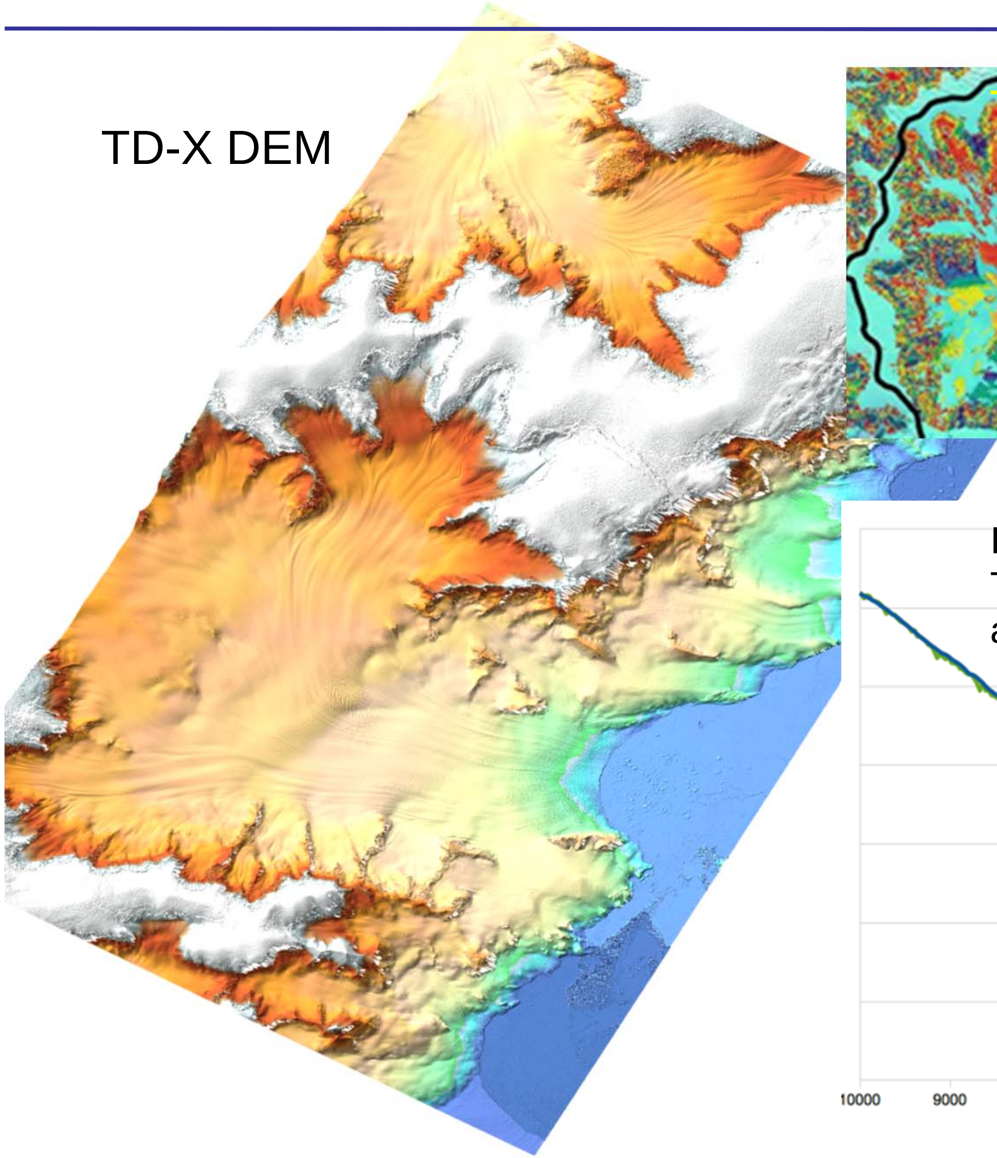
PGC, LI & Larsen-A

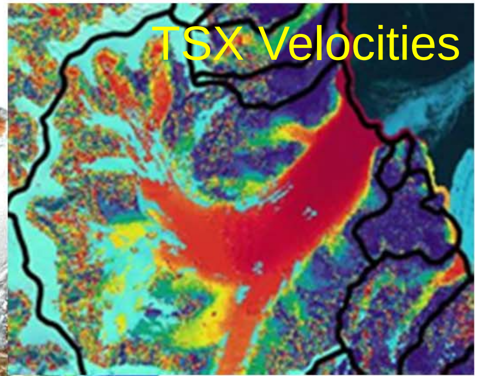


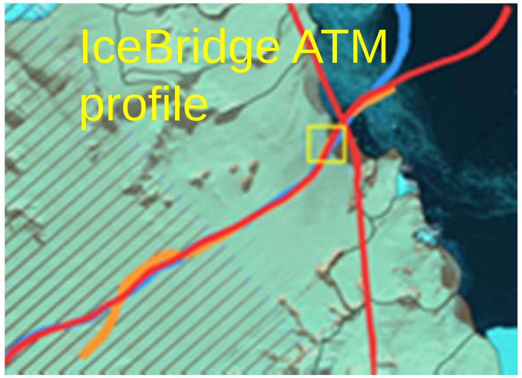
Larsen-B

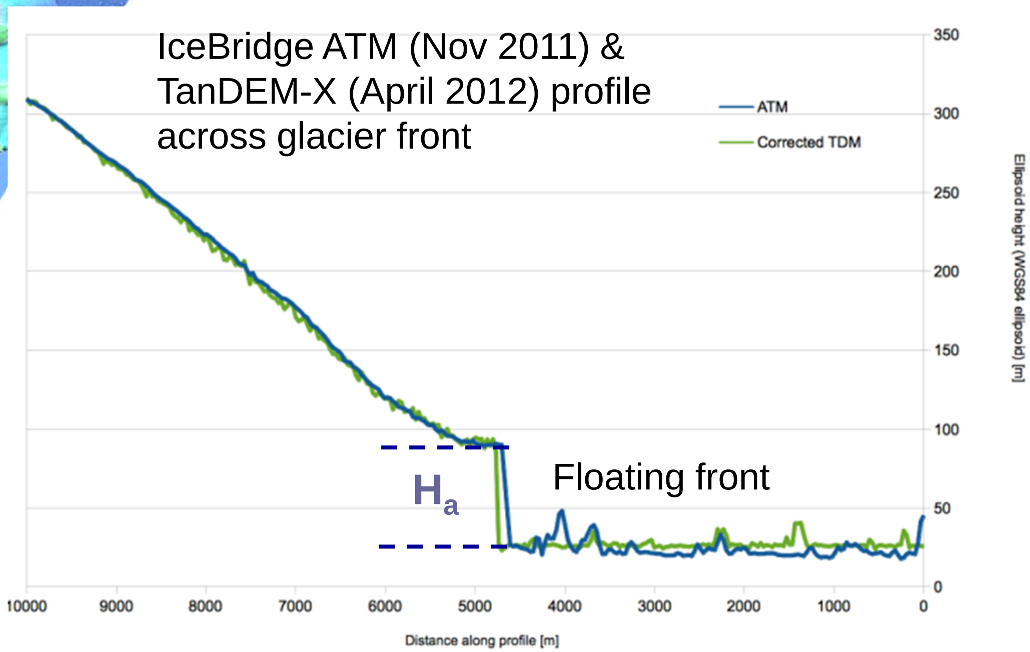


Volume Change and Mass Depletion of Drygalski Glacier

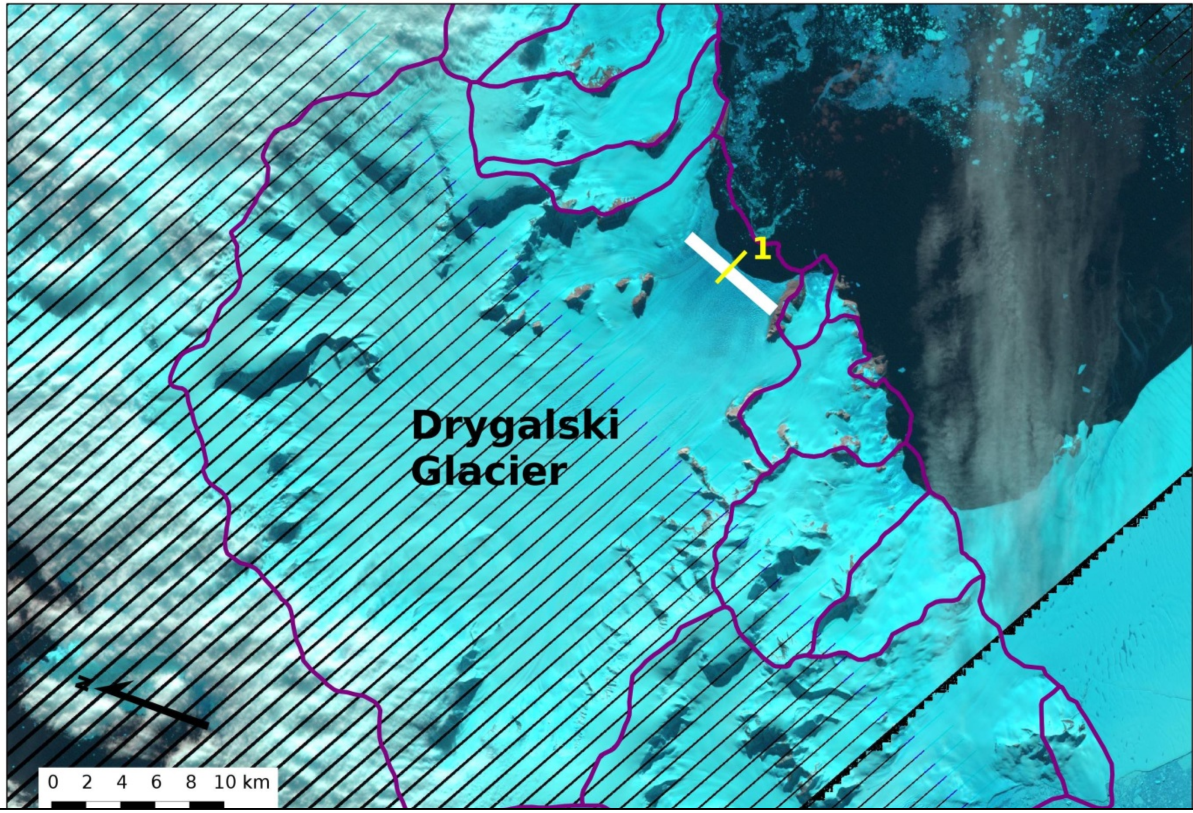




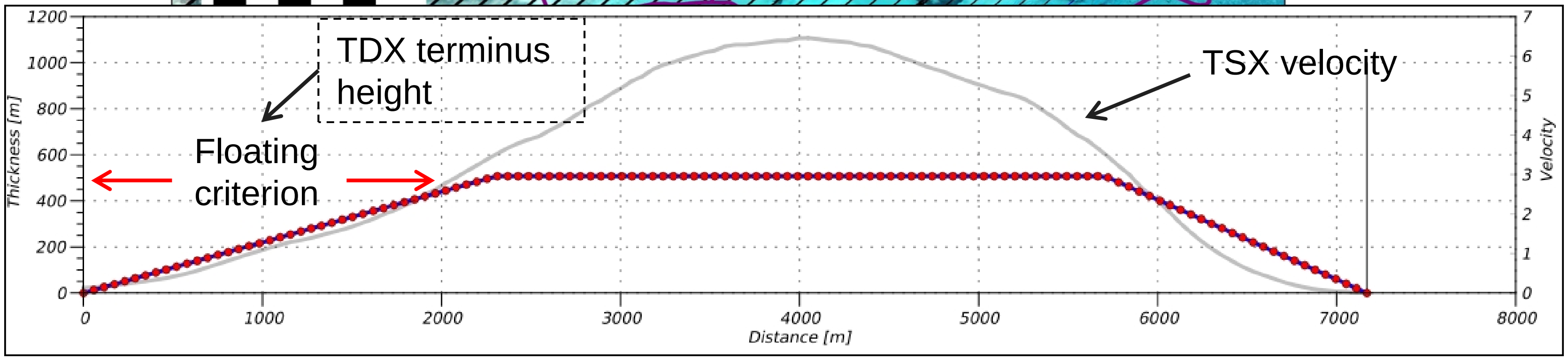




Retrieval of Calving Flux by Means TSX and TDX Data



Landsat -7
1 March 2012



Calving Flux and Mass Balance of PGC and Larsen-A Glaciers

Glacier	Area [km^2]	B_A [Gt a^{-1}]	B_C (2007/2012) [Gt a^{-1}]	B_N [Gt a^{-1}]	b_N [kg m^{-2}a^{-1}]
Sjögren-Boydell	444	0.72	1.04	-0.32	-2342
Pyke	512	0.70	0.64	+0.06	+117
DBE	653	0.93	1.64	-0.71	-1087
Drygalski	1015	1.46	3.80	-2.34	-2305
Boydell-2	127			-0.29	-2300
SB to Dryg.	641			-0.30	-465
Total	***3392***	***3.81***	***7.12***	***-3.88***	

Conclusions

- InSAR Data of TerraSAR-X and TanDEM_X are an excellent basis for measuring glacier topography and volume change, and for retrieving glacier mass balance

- Single pass InSAR has advantages over optical stereo imaging systems for measuring glacier topography and volume change:
  - not affected by clouds; enables systematic surveys
  - good signal is obtained also over snow and firn areas (where optical sensor data are lacking features)

- For InSAR elevation on glaciers the signal penetration needs to be compensated if different SÁR frequencies and/or snow conditions are encountered

- TanDEM-X (together with TSX) offers high spatial resolution and accuracy for measuring topography and topographic change. These missions have the potential to greatly reduce the uncertainty of glacier volume changes and mass balance world-wide.