Winter mass balance of Drangajökull ice cap derived from satellite sub-meter stereo images

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In a nutshell

- Monitoring of ice masses in seasonal time span has important applications in water runoff estimates and helps understanding the relation between climate & glacier changes

- Satellite sub-meter stereo images allow measuring volume changes. Rapid increase of sensors, resolution and accuracy in Digital Elevation Models (DEMs)

Aims of the study:

- Analyze relevant variables in calculation of sub-annual geodetic mass balance (MB). Error assessment.

- Compare results obtained from Remote sensing and in situ measurements

Drangajökull Ice Cap & Data Collected

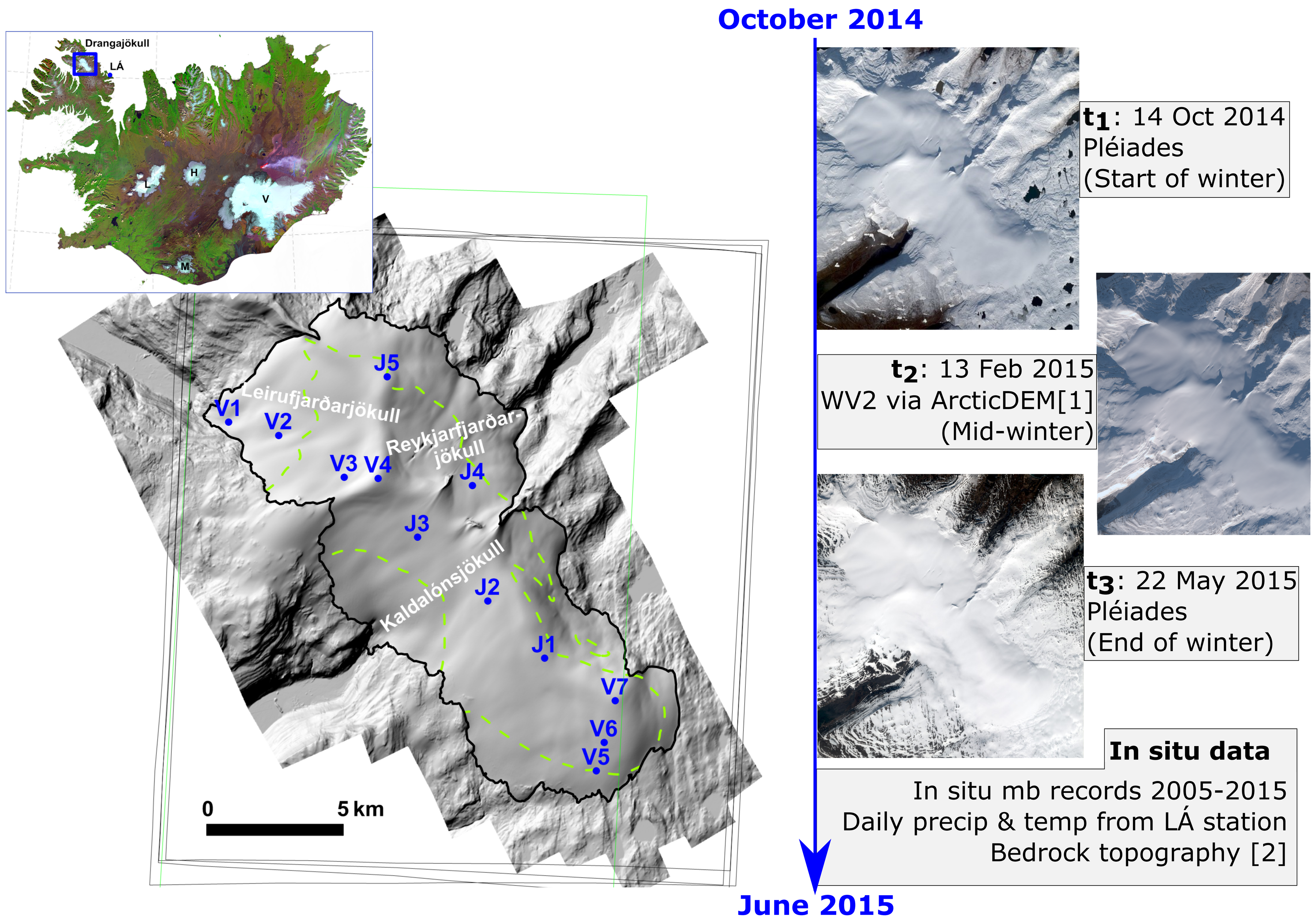


Figure 1: (Left) Location of Drangajökull ice cap (blue square) and the meteorological station (LÁ, blue dot). A lidar DEM covering Drangajökull summer 2011 [3]. The equilibrium line altitude is shown with a green dashed line. Blue dots mark the location of the in situ measurements. Black and green rectangles show the footprints of the Pléiades images and the WV2 DEM, respectively. ***(Right)*** Quick views of the satellite images acquired, and summary of the in situ data compiled.

Processing of satellite stereo-images

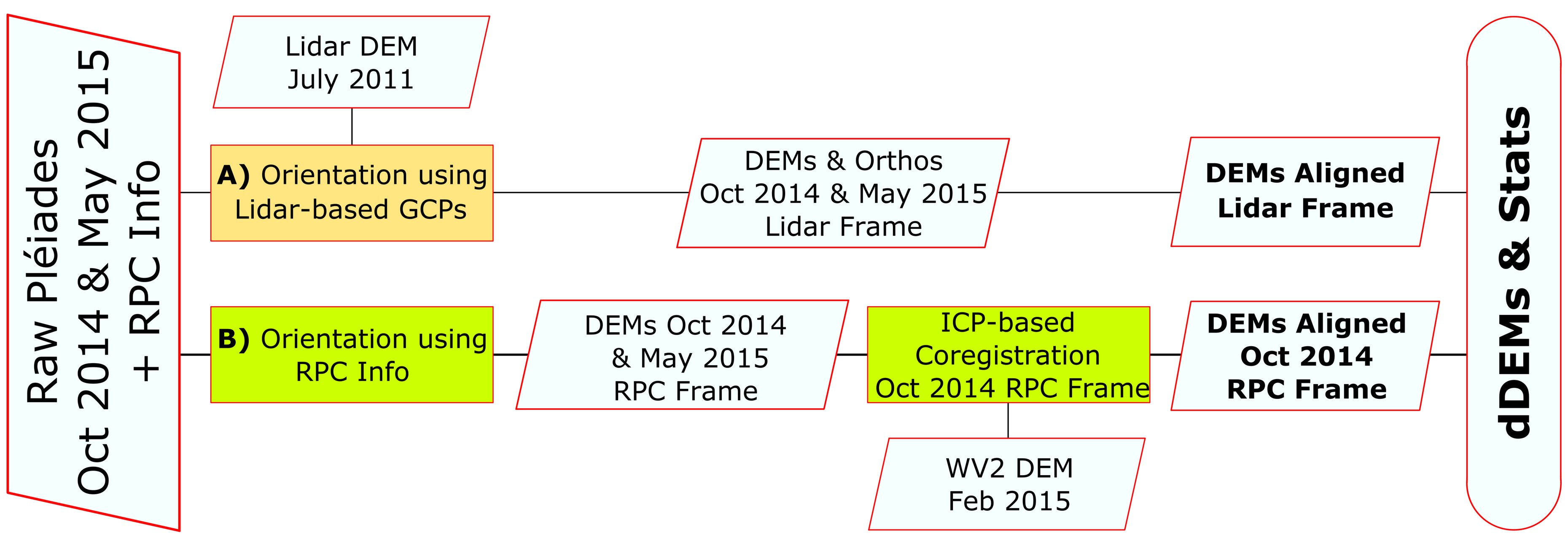


Figure 2: Flowchart of the different schemes studied for obtaining unbiased DEMs and differencial DEMs (dDEMs). Orange squares indicate processing with ERDAS software (Intergraph), and green squares indicate processes with ASP software (NASA).

	N ($\times 10^6$)	Gaps icecap (%)	Mean (m)	Median (m)	NMAD (m)	Mean dH (m)
A - Lidar GCPs	1.4	6.2%	-0.08	-0.05	0.35	5.36
B - ICP	1.6	2.4%	-0.07	-0.02	0.23	5.59
WV2 - ICP	1.0	10.4%	0.08	0.01	0.35	3.84

Table 1: Statistics of the dDEMs in snow- and ice-free areas, and mean elevation difference on the ice cap. The statistics are calculated after masking slopes >20º and shadows.

Maps of elevation difference & Snow accumulation

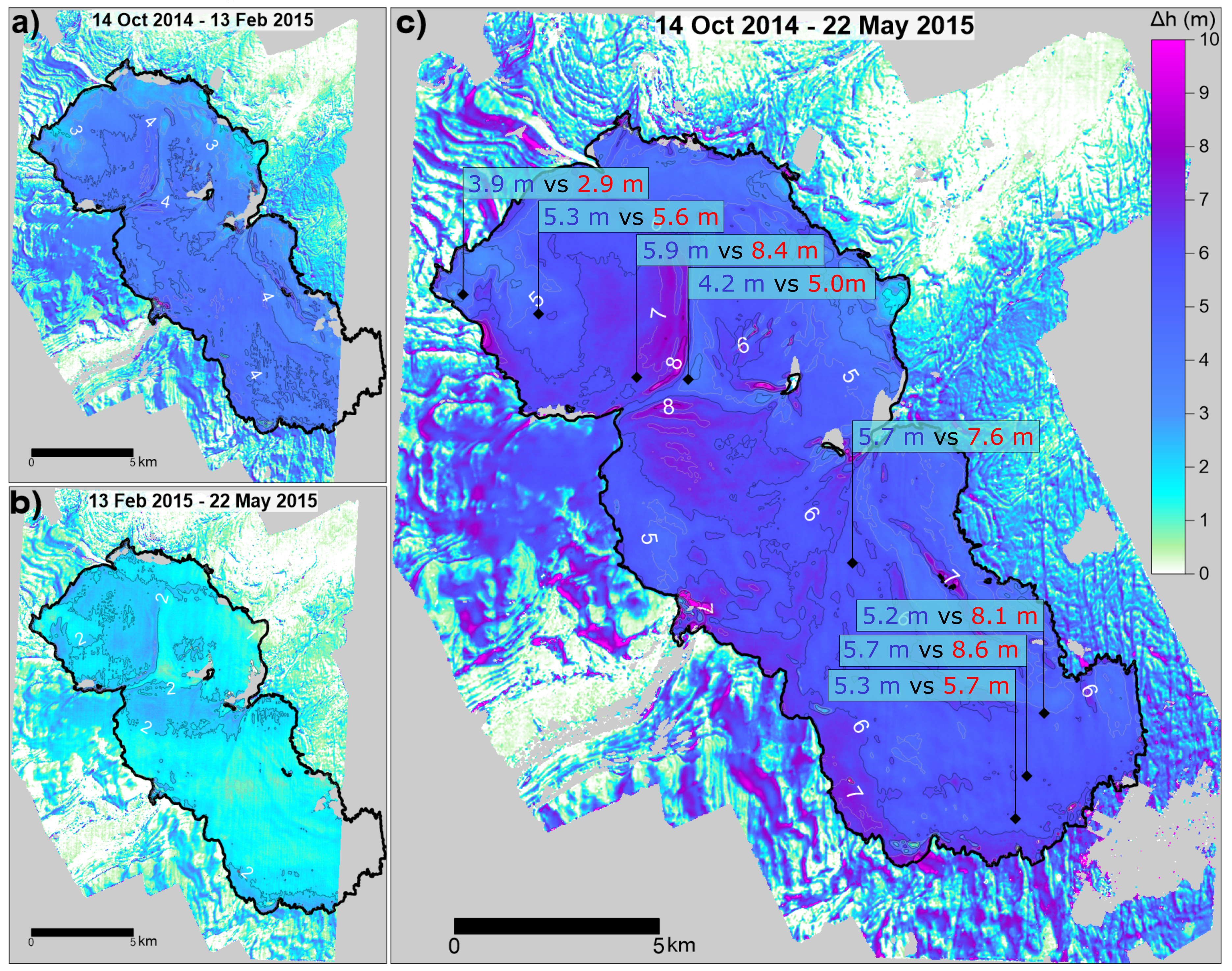


Figure 3: Elevation difference from Pléiades and WV2 DEMs. Labels in **c)** show the elevation difference (Oct 2014-May 2015) versus the snow thickness measured in situ

Glacier-wide geodetic winter mass balance

Satellite obs

$$Bw_{t_1}^{t_f} = \rho_{Snow\,t_f}\left(\bar{h}_{dDEM_{t_1}^{t_f}} + \overline{C_{t_1}^{t_f}}\{h_{Firn}\} + \overline{C_{t_1}^{t_f}}\{\bar{h}_{Snow\,t_1}\}\right)$$

Field obs

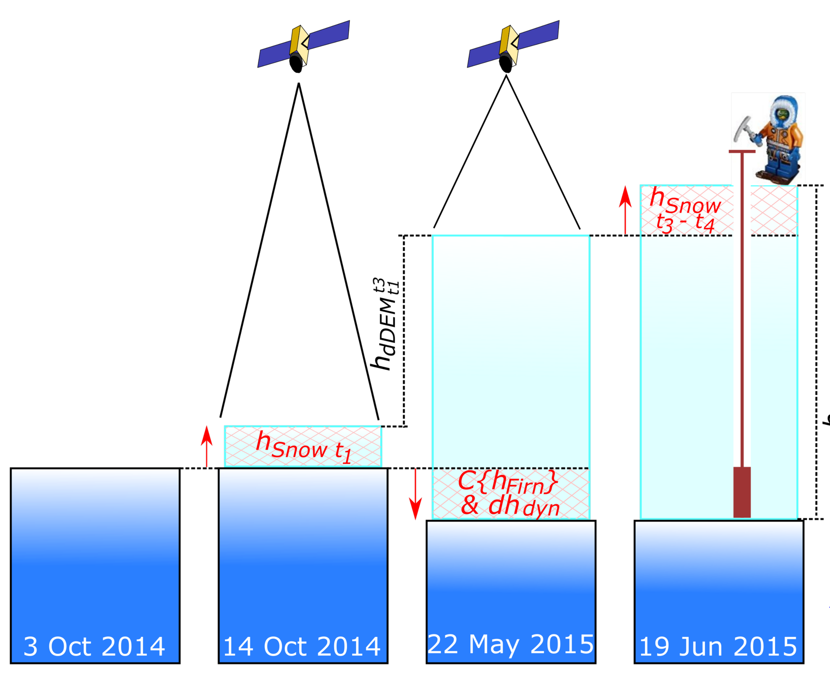
Snow density is crucial and causes large uncertainty

Firn & fresh snow densification underestimates WMB

t	ρ (kg/m^3)	h_{dDEM}	C{h_{Firn}}	C{$h_{Snow\ t1}$}	Δ$B_{\rho Snow}$ (m. w.e.)	**B (m. w.e.)**
14 Oct 2014 - 22 May 2015	554 ± 30	5.58 ± 0.23 m 3.09 ± 0.13 $m_{w.e.}$	0.24 ± 0.12 m 0.13 ± 0.07 $m_{w.e.}$	0.20 ± 0.15 m 0.11 ± 0.08 $m_{w.e.}$	0.16	3.33 ± 0.23 $m_{w.e.}$

Table 2: Glacier-wide geodetic winter mass balance and associated errors. Numbers in blue and red are inferred from satellite and in situ observations, respectively

Pléiades vs in situ



In situ: Snow accumulated 3 Oct 2014 - 19 Jun 2015
Pléiades: Elevation diff 14 Oct 2014 - 22 May 2015

Comparison requires correction (↑&↓) for:
- -Time mismatch -> Degree-day model
- -Firn compaction -> Previous year mb records
- -Ice dynamics -> Ice-flow model

$$cdDEM_{t_1}^{t_3} = h_{dDEM_{t_1}^{t_3}} + C\{h_{Firn}\} + h_{Snow\,t_1} + h_{Snow\,t_3-t_4} + dh_{dyn}$$

Point	h_{Snow} (m)	h_{dDEM} (m)	C{h_{Firn}} (m)	C{h_{Snow}} (m)	dh_{dyn} (m)	ch_{dDEM} (m)	Res (m)
V3	8.38	5.86	0.58	1.05	1.16	8.64	-0.26

Figure 4 (left): Sketch of different factors (red text with red arrows) affecting the comparison between glaciological and geodetic methods. ***Table 3 (right):*** Example of comparison of snow thickness and elevation difference from Pléiades DEMs over point V3, including the corrections applied pointwise to the dDEM to make them comparable to the in situ measurements.

Conclusions

- Pléiades & WV - based DEMs show relative accuracy of 0.2 - 0.3 m (slopes <20º) and the processing chain does not require GCPs -> suitable for measuring snow accumulation in areas with enough mass balance amplitude (> 1 m w.e.)

-Glacier-wide geodetic winter mass balance depends on accurate estimates of snow density and firn & fresh snow densification. Densification produces systematic but minor (4%) increase to the mass balance obtained from satellite.

-Geodetic mass balance is B = 3.33 ± 0.23 m w.e. between October-May 2014. Uncertainty in sub annual periods of time ranges 0.2 to 0.4 m w.e.

-Geodetic and glaciological methods are in agreement after accounting for: (1) difference in time between measurements (2) firn compaction (3) ice emergence & submergence.

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