The Cryosphere Discuss., https://doi.org/10.5194/tc-2017-272
Manuscript under review for journal The Cryosphere
Discussion started: 5 January 2018

The Cryosphere Discussions
Open Access
EGU

Brief communication: Unabated wastage of the Juneau and Stikine icefields (southeast Alaska) in the early 21st century

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Abstract. The large Juneau and Stikine icefields (Alaska, JIF and SIF) lost mass rapidly in the second part of the 20th century. Laser altimetry, gravimetry and sparse field measurements suggest continuing mass loss in the early 21st century. However, two recent studies based on time series of SRTM and ASTER digital elevation models (DEMs) indicate a slowdown in mass loss after 2000. Here, the ASTER-based geodetic mass balance is recalculated, carefully avoiding the use of the SRTM DEM because of the unknown penetration depth of the C-Band radar signal. We find strongly negative mass balances from 2000 to 2016 (-0.68±0.15 m w.e. a^{-1} for JIF and -0.83±0.12 m w.e. a^{-1} for SIF), in agreement with laser altimetry, confirming that mass losses are continuing at unabated rates for both icefields. The SRTM DEM should be avoided or used very cautiously to estimate glacier volume change, especially in the North Hemisphere and over timescales of less than ~20 yrs.

1 Introduction

The Juneau Icefield (JIF) and Stikine Icefield (SIF) are among the largest and southernmost icefields in Alaska. The JIF covers about 3800 km² and the SIF close to 6000 km² at the border between southeast Alaska and Canada (Kienholz et al., 2015). Together they account for roughly 10% of the total glacierized area in Alaska. Both icefields experienced rapid mass loss in the second part of the 20th century (Arendt et al., 2002; Berthier et al., 2010; Larsen et al., 2007). Spaceborne gravimetry and laser altimetry data suggest continuing rapid mass loss in southeast Alaska between 2003 and 2009 (Arendt et al., 2013).

For the JIF, Larsen et al. (2007) found a negative mass balance of -0.62 m w.e. a^{-1} for a time interval starting in 1948/1982/1987 (depending on the map dates) and ending in 2000, the date of acquisition of the shuttle radar topographic mission (SRTM) digital elevation model (DEM). Berthier et al. (2010) found a slightly less negative multi-decadal mass balance (-0.53 ± 0.15 m w.e. a^{-1}) from the same starting dates as Larsen et al. (2007) to a final DEM acquired in 2007. Repeat airborne laser altimetry

are available for nine glaciers of the JIF (Larsen et al., 2015) with a first survey performed in 1993 (2 glaciers), 1999 (1 glacier) and 2007 (6 glaciers). The last survey used in Larsen et al. (2015) was flown in 2012 for all glaciers. During these varying time intervals, nine glaciers experienced strongly negative mass balances (between -0.51 and -1.14 m w.e. a^{-1}) while Taku Glacier, which alone accounts for one fifth of the JIF area, experienced a slightly positive mass balance (+0.13 m w.e. a^{-1}). Further, the glaciological measurements performed on Lemon Creek Glacier (11.8 km² in 1998) suggest accelerated mass loss since the mid-eighties: the glacier-wide mass balance declined from -0.30 m w.e. a^{-1} during 1953-1985 to -0.60 m w.e. a^{-1} during 1986-2011 (Pelto et al., 2013). A modelling study also found a negative mass balance for the entire JIF (-0.33 m w.e. a^{-1}) for 1971-2010 (Ziemen et al., 2016). Their 40-year mass balance is a result of glacier mass stability until 1996 and rapid mass loss afterwards. Taken together, all these studies point toward rapid mass loss of the JIF and accelerated wastage during the last ~20 years. Conversely, a study based on the SRTM DEM and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) multi-temporal DEMs found a JIF mass balance only moderately negative at -0.13 ± 0.12 m w.e. a^{-1} from 2000 to 2009/2013 (Melkonian et al., 2014).

Only a few estimates of mass change are available on the larger and more remote SIF. Three of its glaciers were surveyed with airborne laser altimetry from 1996 to 2013 and all experienced rapid mass loss. The glacier-wide mass balances were -0.71, -0.98 and -1.19 m w.e. a^{-1} for, respectively, Baird, Le Conte and Triumph glaciers. Based on DEM differencing over several decades, Larsen et al. (2007) and Berthier et al. (2010) found SIF-wide mass balance of, respectively, -1.48 and -0.76 ± 0.12 m w.e. a^{-1}. A recent estimate based on the SRTM and ASTER DEMs suggest a less negative icefield-wide mass balance of -0.57 ± 0.18 m w.e. a^{-1} from 2000 to 2014 (Melkonian et al., 2016).

If correct, Melkonian et al. (2014, 2016)'s estimates would imply a considerable slowdown of the mass loss of the Juneau and, to a smaller extent, Stikine icefields during the first decade of the 21st century. However, no clear trend in climate such as cooling or increased precipitation was found during this period to explain such a slow down (Melkonian et al., 2014; Ziemen et al., 2016). Further, Melkonian et al. (2014, 2016)'s estimates used as starting elevation measurement the C-Band SRTM DEM acquired in February 2000, the core of winter in Alaska. The C-Band radar signal is known to penetrate into the cold winter snow and firn such that SRTM maps a surface below the real glacier surface which can bias the elevation change measurements (e.g., Berthier et al., 2006; Rignot et al., 2001). Melkonian et al. (2014, 2016) accounted for this penetration by subtracting the simultaneous C-Band and X-Band SRTM DEM, assuming no penetration of the X-Band DEM (Gardelle et al., 2012), the best available correction at the time of their study. However, this strategy is not appropriate given that the X-band penetration depth has recently been recognized to reach several meters (e.g., Dehecq et al., 2016; Round et al., 2017). In this context, the goal of this brief communication is to recalculate the early 21st century geodetic mass balances of the Juneau and Stikine icefields using multi-temporal ASTER DEMs, carefully excluding the SRTM DEM to avoid a likely penetration bias.

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2 Data, methods and uncertainties

The data and methodology applied to the JIF and SIF were identical to the ones used in a recent study deriving region-wide glacier mass balance in High Mountain Asia (Brun et al., 2017). The reader is thus referred to the latter study for details. Only the main processing steps are briefly presented here.

ASTER DEMs were calculated using the open-source Ames Stereo Pipeline (ASP) (Shean et al., 2016) from 3N (nadir) and 3B (backward) images acquired between 2000 and 2016. All images with cloud coverage lower than 80% were selected, resulting in 153 stereo pairs for the JIF and 368 stereo pairs for the SIF. Images intersecting less than 0.5% of the icefield areas were excluded, reducing the number of stereo pairs to 114 for the JIF and 284 for the SIF. Planimetric and altimetric offsets of each ASTER DEM were corrected using the SRTM DEM as a reference. Offsets were determined on stable terrain, masking out glacierized areas using the Randolph Glacier Inventory v5.0 (Pfeffer et al., 2014). The RGI v5.0 glacier outlines for both the JIF and SIF were mapped using imagery from August of 2004 and 2005.

For the JIF only, we also downloaded directly the ASTER DEMs available online from the LPDAAC website (called 14DMO) because they were used in Melkonian et al. (2014, 2016). The goal is to test the sensitivity of the JIF-wide mass balance to the ASTER DEM generation software. 3D coregistration of the 14DMO DEMs was performed using the same steps as the ASP DEMs. Unlike the ASP DEMs, the 14DMO DEMs contain no data gaps, as they are filled by interpolation.

From the time series of 3D-coregistered ASTER DEMs, the rate of elevation changes (*dh/dt* in the following) was extracted for each pixel of our study domain in two steps (Berthier et al., 2016). The SRTM DEM was excluded when extracting the final *dh/dt*. *dh/dt* were calculated for the entire period (from 2000 to 2016) and also for different sub-periods for the sake of comparability to published mass balance estimates.

For both icefields and in each 50-m altitude interval, *dh/dt* lying outside of ±3 normalized median absolute deviations (NMAD) were considered as outliers. We further excluded all *dh/dt* measurements for which the error in the linear fit is larger than 2 m a^{-1}. The total volume change rate was calculated as the integral of the mean *dh/dt* over the area altitude distribution. The icefield-wide mass balance was obtained using a volume-to-mass conversion factor of 850 ± 60 kg m^{-3} (Huss, 2013). The same procedure was followed to compute the glacier-wide mass balances of selected individual glaciers for which mass balances were estimated from repeat laser altimetry surveys (Larsen et al., 2015).

Uncertainties for *dh/dt* were computed using the tile method as in Berthier et al. (2016). Splitting the off-glacier terrain in 4 by 4 tiles, we found uncertainties of 0.03 m a^{-1} for JIF and 0.04 m a^{-1} for SIF from 2000 to 2016. When data gaps occurred in the *dh/dt* map, we conservatively multiplied these uncertainties by a factor of five.

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3 Results

Rate of elevation changes for the two icefields from 2000 to 2016 are mapped in Figure 1. Most glaciers thinned rapidly in their lower parts and experienced limited elevation change in their upper reaches. Thinning rates as negative as 9 m a^{-1} are observed. Taku Glacier (south of the JIF) is an exception with thickening of up to 4 m a^{-1} at its glacier front.

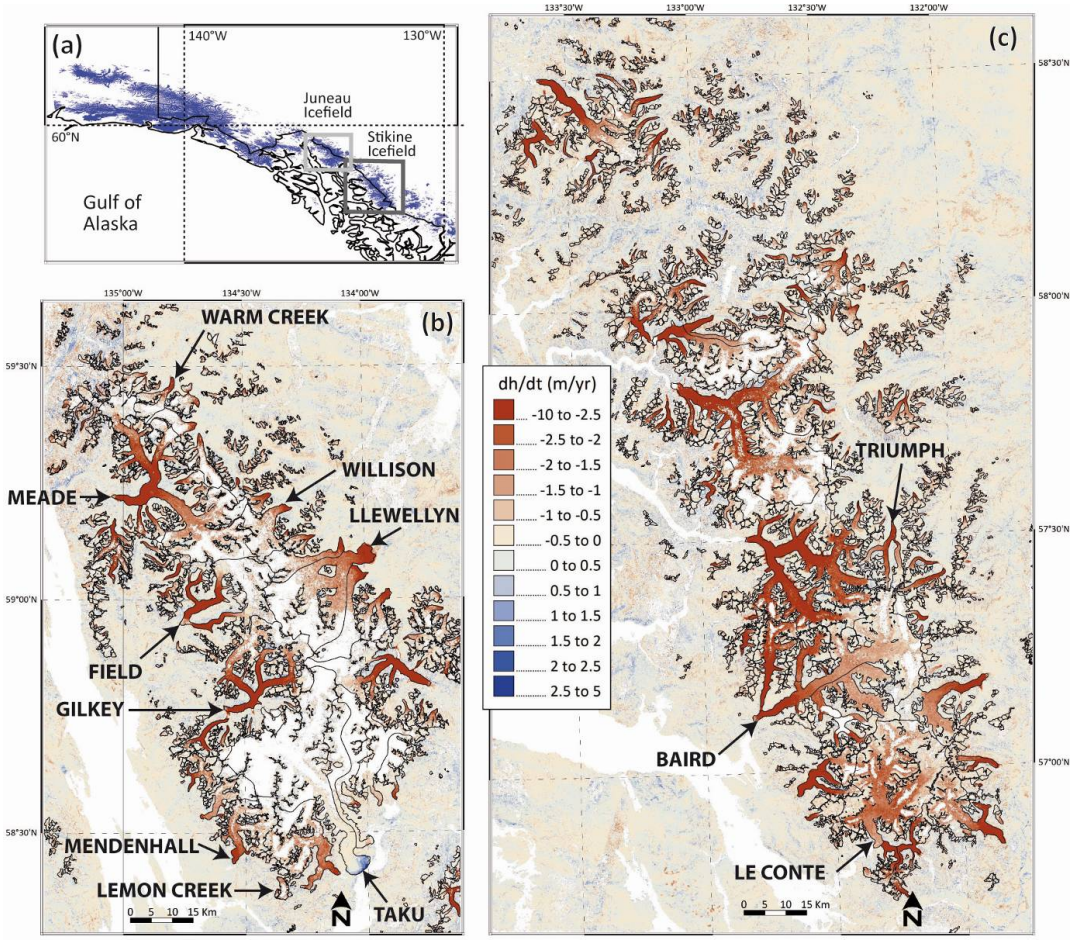

Figure 1: Rate of elevation changes for the Juneau and Stikine icefields from 2000 to 2016. (a) Location of the two icefields in southeast Alaska. Rate of elevation changes (*dh/dt*) for the JIF (b) and (c) for the SIF. Glacier outlines are from RGI v5.0. Glaciers surveyed by airborne laser altimetry are labelled. The horizontal scale and the color code are the same for the two maps. Areas in white correspond to data gaps.

The 2000-2016 mass balances are clearly negative for both icefields at -0.68±0.15 m w.e. a^{-1} for JIF (59% coverage with valid data) and -0.83±0.12 m w.e. a^{-1} for SIF (81% coverage with valid data). If we apply the linear regression analysis to a subset of the ASTER DEMs to match the time periods studied by Melkonian et al. (2014, 2016), the icefield-wide mass balances remain mostly unchanged: -0.64±0.14 m w.e. a^{-1} for JIF from 2000 to 2013, 44% coverage with valid data; -0.78±0.17 m w.e. a^{-1} for

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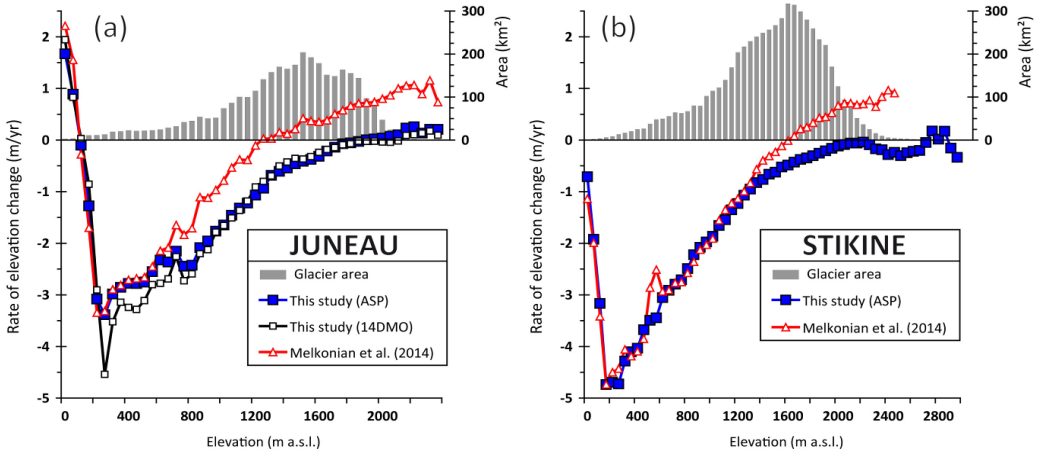
133 SIF from 2000 to 2014, 55% coverage with valid data. Our values are 0.51 m w.e. a^{-1} (JIF) and 0.21 m
134 w.e. a^{-1} (SIF) more negative than in Melkonian et al. (2014, 2016) and statistically different for the JIF.
135
136 The coverage with valid *dh/dt* data drops rapidly for both icefields when shorter time periods are
137 considered. For example, the percentage of valid data is reduced to 8% (respectively 25%) only on the
138 JIF when the 2000-2008 (respectively 2008-2016) period is analyzed. Thus, the ASTER multi-temporal
139 analysis is not appropriate to measure mass balance over periods shorter than 10 years for these two
140 Alaskan icefields. This is due to the presence of many cloudy images and, for cloud-free scenes, to a
141 large percentage of data gaps in individual ASTER DEMs over the accumulation areas of the icefields,
142 a direct result of the limited contrast in the ASTER stereo-images over textureless snow fields.
143
144 In Figure 2, *dh/dt* are plotted as a function of altitude and compared to the values in Melkonian et al.
145 (2014, 2016). To enable a more direct comparison, we applied the same criteria to average their *dh/dt*
146 in 50-m altitude bands and exclude outliers. We also considered the same periods, from 2000 to 2013
147 for the JIF and from 2000 to 2014 for the SIF. In the case of the SIF (Figure 2b), we also added the
148 *dh/dt* obtained by applying our method to the 14DMO DEMs.
149



150

151 **Figure 2:** Rates of elevation change vs. elevation for the JIF from 2000 to 2013 (a) and for the SIF from 2000 to 2014 (b).
152 Results from this study are compared to the *dh/dt* values obtained in two earlier studies using a similar method (Melkonian et
153 al., 2014, 2016). The grey histograms show the area-altitude distribution.
154
155 For the JIF, an excellent agreement is found between the *dh/dt* values obtained in this study using the
156 ASP and 14DMO DEMs, except maybe between 250 and 600 m a.s.l. (5% of the icefield area) where
157 the thinning rates are about 0.5 m a^{-1} more negative using the 14DMO DEMs. The area-weighted
158 mean absolute difference between these two curves (ASP and 14DMO) is 0.09 m a^{-1}. The Melkonian
159 et al. (2014) *dh/dt* generally agree with ours below 600 m a.s.l. Above this elevation, their values are
160 systematically more positive. The difference reaches 0.7 m a^{-1} at 800 m a.s.l. and then remains more

or less stable, around 0.7-0.9 m a^{-1}. Melkonian et al. (2014) data suggests thickening of the areas above 1350 m a.s.l. where 62% of the JIF area is located.

For SIF, a good agreement is found between ours and Melkonian et al. (2016)'s *dh/dt* below an elevation of 1300 m a.s.l. Above 1300 m the two curves diverge. Our *dh/dt* are becoming less negative until 2100 m a.s.l. where they become indistinguishable from 0 m a^{-1} up to the SIF highest elevation band. Conversely, in the Melkonian et al. (2016) dataset, *dh/dt* increases rapidly, crossing 0 m a^{-1} at ~1650 m a.s.l., finally arriving at a thickening rate of > 0.7 m a^{-1} above 2000 m a.s.l. Thus the difference in SIF-wide mass balance between the two dataset is due to difference in *dh/dt* above 1300 m a.s.l., where 66% of the SIF icefield area is found.

Comparison of our *dh/dt* estimates to the ones derived from repeat laser altimetry data is not straightforward because the survey periods differ. For example, for the JIF, six out of nine glaciers were sampled for the first time in 2007. In most cases, it would be technically possible to use a temporal subset of the ASTER DEMs to match the time period of altimetry surveys but, as said above, this would be at the cost of the coverage in our *dh/dt* maps and would lead to much more uncertain mass balance estimates. Consequently, we preferred to extract *dh/dt* and the individual glacier mass balance for the longest available time period in the ASTER series (from 2000 to 2016) in order to maximize coverage and thus minimize uncertainties. The pattern of *dh/dt* with altitude for individual glaciers is in broad agreement between laser altimetry and our ASTER-based results (Supplementary Figure S1). Importantly, for both dataset, no clear thickening was observed in the accumulation areas of glaciers. When individual elevation bins of 50 m are considered, averaged differences between *dh/dt* from laser altimetry and the ASTER DEMs are typically 0.2 to 0.3 m a^{-1} for individual glaciers. This level of error is similar to the one found previously for the ASTER method in the Mont-Blanc area (Berthier et al., 2016). Glacier-wide mass balances for individual glaciers match well (Table 1).

The mean mass balance of these 12 glaciers is nearly the same (-0.73 and -0.74 m w.e. a^{-1}) using the two techniques. The standard deviation of the mass balance difference is 0.18 m w.e. a^{-1} (n=12). For 60 individual glaciers larger than 2 km² in High Mountain Asia, Brun et al. (2017) also found a standard deviation of 0.17 m w.e. a^{-1} between the ASTER-based and published glacier-wide mass balance estimates. In the very different geographic context of large maritime glaciers of southeast Alaska, we confirm here their uncertainty estimate for individual glaciers in High Mountain Asia.

Our results are also in good agreement with field (glaciological) measurements on Taku Glacier. Pelto et al. (2013) found a mass balance of -0.01 m w.e. a^{-1} between September 2000 and September 2011. We derived the same mass balance (-0.01 ± 0.16 m w.e. a^{-1}) from ASTER DEMs acquired between 2000 and 2016. Conversely, Melkonian et al. (2014)'s mass balance for Taku Glacier was strongly positive at +0.44 ± 0.15 m w.e. a^{-1}.

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Table 1. Glacier-wide mass balances (B_a) of 12 individual glaciers of the JIF and SIF derived from airborne laser altimetry for different periods (Larsen et al., 2015) and calculated in this study using ASTER DEMs from 2000 to 2016.

Icefield/Glacier	Area km²	Laser period	B_a Laser m w.e. a^{-1} (Larsen et al., 2015)	B_a ASTER m w.e. a^{-1} (this study)
Juneau	**3398**			**-0.68**
Field	187	2007-2012	-0.94	-0.93
Gilkey	223	2007-2012	-0.75	-0.99
Lemon Creek	9	1993-2012	-0.91	-0.78
Llewellyn	435	2007-2012	-0.61	-0.70
Meade	446	2007-2012	-1.03	-0.88
Mendenhall	106	1999-2012	-0.57	-0.73
Taku	711	1993-2012	0.13	-0.01
Warm Creek	39	2007-2012	-0.67	-0.71
Willison	79	2007-2012	-0.51	-0.69
Sum/Mean 9 glaciers	**2234**		**-0.65**	**-0.71**
Stikine	**5805**			**-0.83**
LeConte	56	1996-2013	-0.98	-0.93
Baird	435	1996-2013	-0.71	-0.70
Triumph	356	1996-2013	-1.19	-0.86
Sum/Mean 3 glaciers	**847**		**-0.96**	**-0.83**
Mean all 12 Glaciers			**-0.73**	**-0.74**

4 Discussion

We find an excellent agreement between repeat laser altimetry survey and our multi-temporal analysis of ASTER DEMs both in term of mass balances and pattern of *dh/dt* with altitude for the JIF and SIF since 2000 (Supplementary Figure S1). Our results also suggest that the limited number of glaciers sampled using laser altimetry are representative of the icefields as a whole. This is rather expected for the JIF because 9 glaciers covering a large fraction of the icefield (66%) were monitored using airborne data but not straightforward for the SIF where only 3 glaciers, accounting for 15% of the total icefield area, were surveyed.

213 This agreement between our ASTER results and airborne laser altimetry, together with the fact that
214 most studies point toward steady or accelerating mass losses in southeast Alaska (see introduction),
215 suggest that the mass balance is overestimated in Melkonian et al. (2014, 2016). There are two main
216 differences between Melkonian et al. (2014, 2016)'s method and ours that could explain these
217 contending mass balances: (i) they did not generate the DEM themselves but directly download the
218 14DMO product from the LPDAAC website and (ii) they used the SRTM DEM as a starting elevation in
219 their regression analysis to compute *dh/dt*.
220
221 To test the sensitivity of our results to the ASTER DEM generation software, we applied our processing
222 chain (in particular, excluding the SRTM DEM to infer the final *dh/dt*) to the 14DMO DEMs. From 2000
223 to 2016, we found a JIF-wide mass balance of -0.67±0.27 m w.e. a^{-1}, in striking agreement with the
224 value derived from ASP DEMs (-0.68±0.15 m w.e. a^{-1}). The pattern of *dh/dt* with elevation is also in
225 excellent agreement (Figure 2a). Uncertainties are nearly doubled when applying our method to the
226 14DMO DEMs: this is explained by larger errors of *dh/dt* off glacier (0.06 m a^{-1} for 14DMO DEMs vs.
227 0.03 m a^{-1} for ASP DEMs) and a lower coverage of the JIF with valid *dh/dt* data (49% for 14DMO
228 DEMs vs. 59% for ASP DEMs). The latter may appear counter-intuitive as the 14DMO DEMs are
229 delivered with no data gaps. The larger percentage of data gaps in the final 14DMO *dh/dt* maps results
230 from the higher noise level of the individual 14DMO DEMs and demonstrate the efficiency of our filters
231 to exclude unreliable *dh/dt* values.
232
233 Thus, we conclude that a likely explanation why Melkonian et al. (2014, 2016) found too positive mass
234 balance for the JIF and, to a lesser extent, for the SIF is associated with the SRTM DEM and in
235 particular the penetration of the C-Band radar signal into cold winter snow and firn. This interpretation
236 is further supported by the fact that *dh/dt* curves nicely agree in the ablation areas where SRTM
237 penetration depth is negligible and diverge in the accumulation areas where the largest penetration
238 depths are expected (Figure 2). As noted in the introduction, Melkonian et al. (2014, 2016) attempted
239 to account for this by subtracting the C-Band and X-Band SRTM DEM, assuming no penetration of the
240 X-Band DEM (Gardelle et al., 2012). However, studies have measured X-band penetration depth of
241 several meters (e.g., Dehecq et al., 2016; Round et al., 2017). In the case of the SIF, Melkonian et al.
242 (2016) assumed no penetration below 1000 m a.s.l. and 2 m for elevations above 1000 m. Aware of
243 how uncertain this correction was, these authors also proposed (their supplementary material section
244 6.3 and, Table S4) a different correction with no penetration below 1000 m a.s.l. and a linear increase
245 from 2 to 8 m from 1000-2500 m a.s.l. Using this alternative scenario, they found an icefield-wide mass
246 balance of -0.85 m w.e. a^{-1}, in better agreement with our value of -0.78±0.17 m w.e. a^{-1} from 2000 to
247 2014. Their 2 to 8 m penetration depth is consistent with the penetration gradient we inferred here by
248 subtracting the SRTM DEM from a reconstructed DEM, obtained by extrapolating *dh/dt* to the time of
249 acquisition of the SRTM as proposed in Wang and Kääb (2015). This is also consistent with a first-
250 order estimate of the penetration depth inferred from the elevation difference between the SRTM DEM
251 and laser altimetry profiles acquired in late August 1999 and May 2000 over Baird and Taku glaciers.

However, the latter estimates should be considered with care considering the complexity to account for seasonal elevation changes, long term elevation changes and the difficulty to estimate the vertical offset between the two elevation dataset on ice-free terrain.

The fact that the positive bias in Melkonian et al. (2014, 2016) mass balances was larger for the JIF and than for the SIF suggests a larger SRTM penetration depth for the JIF. It indicates that the penetration is probably spatially variable (depending on the firn conditions in February 2000) such that a correction determined on a single icefield (or worse a single glacier) may not apply to neighbouring glacier areas.

Larsen et al. (2007) used the SRTM DEM as their final topography after applying a linear correction of SRTM with altitude (2.6 m per 1000 m elevation, with a -2.5 offset at 0 elevation) determined by comparing SRTM to August 2000 laser altimetry data. Such a correction would correspond to a maximum SRTM penetration of ~1.5-2 m above 1500 m a.s.l. much smaller than what we found here. Thus, the fact that SRTM penetration depth is larger than previously thought over southeast Alaska icefields may also explain why Larsen et al. (2007) found larger mass losses than Arendt et al. (2002) and Berthier et al. (2010) who both used only non-penetrating optical (Lidar or stereo-imagery) data.

An uneven seasonal distribution of the ASTER DEMs could bias the multi-annual mass balances derived using the ASTER method is linked to the (Berthier et al., 2016). This is especially crucial in maritime environment such as southeast Alaska where large seasonal height variations are expected. As in the case of the Mont-Blanc area (Figure 6 in Berthier et al., 2016), we sampled an hypothetic seasonal cycle in surface elevation changes at the time of acquisition of all ASTER DEMs over the JIF and fitted a linear regression to the elevation change time series. Assuming a seasonal amplitude as large as 10 m, the slope of the regression line is very close to 0 (-0.007 m a^{-1}) suggesting no seasonal bias in the dates of the ASTER DEMs. To confirm the lack of seasonal bias and because the majority of the ASTER images were acquired close to accumulation peak, we also calculated a mass balance for the JIF considering only the 61 ASTER DEMs acquired in March, April and May between 2000 and 2016. For this alternative mass balance estimate, the coverage with valid data is reduced to 38%. At -0.58±0.18 m w.e. a^{-1}, the JIF-wide mass balance is slightly less negative but not statistically different from the "all seasons" value (-0.68±0.15 m w.e. a^{-1}, 59% of valid data). The pattern of *dh/dt* with altitude is also very similar.

5 Conclusion

In this study, we show that the Juneau and Stikine icefields continued to lose mass rapidly from 2000 to 2016. The mass balances from repeat airborne laser altimetry and multi-temporal ASTER DEMs are reconciled if the SRTM DEM is discarded when extracting the rate of elevation change on glaciers from the elevation time series. Multi-temporal analysis of DEMs derived from satellite optical stereo-imagery

is thus a powerful method to estimate geodetic region-wide mass balances over time intervals of, typically, more than 10 years. The strength of the ASTER method lies in the fact that it is based on an homogeneous and continuous archive of imagery built since 2000 using the same sensor. Maintaining openly available medium- to high-resolution stereo capabilities should be a high priority among space agencies in the future.

Previously published mass balances for these Alaska icefields using SRTM and ASTER DEMs were likely biased positively because of the strong penetration of the C-Band and X-Band radar signal into the cold winter snow and firn in February, when the SRTM was flown. Accounting for this penetration by subtracting the C-Band and X-Band SRTM DEMs (as often done before) is not appropriate because the X-Band penetration depth can reach several meters. Caution should thus be used when deriving mass balance using SRTM and Tandem-X DEMs over time period of less than ~20 years. Comparing DEMs acquired at the same time of the year using the same radar wavelength (e.g., Neckel et al., 2013) is one promising strategy to limit the bias due to differential radar penetration.

Acknowledgements

We thank Fanny Brun for sharing her python codes. We thank the Global Land Ice Measurement from Space (GLIMS) project that allowed the population of a vast archive of ASTER stereo images over glaciers. E.B. acknowledges support from the French Space Agency (CNES) and the Programme National de Télédétection Spatiale grant PNTS-2016-01.

Author contributions

E.B. designed the study, made the data analysis and lead the writing. C.L. provided the laser altimetry data. W.D., M.W. and M.P. provided unpublished results. All authors discussed the results and wrote the paper.

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