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Further summer speedup of Jakobshavn Isbræ

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Abstract

We have extended the record of flow speed on Jakobshavn Isbræ through the summer of 2013. These new data reveal large seasonal speedups, 30 to 50 % larger than previous summers. At a point a few kilometres inland from the terminus, the mean annual speed for 2012 is nearly three times as large as that in the mid 1990s, while the peak summer speeds are more than a factor of 4 greater. These speeds were achieved as the glacier terminus retreated to the bottom of an overdeepened basin with a depth of ~1300 m below sea level. While retreat may slow slightly as the terminus retreats farther – to a moderate rise in the bed – it is likely to reach the deepest section of the trough within a few decades, at which point it should rapidly retreat to the shallower regions ~50 km farther upstream, potentially by the end of this century.

1 Introduction

The speeds of many of Greenland glaciers have varied dramatically over the last two decades (Howat et al., 2008; Moon et al., 2012; Rignot and Kanagaratnam, 2006), which has contributed to the ice sheet's increasingly negative mass imbalance (Shepherd et al., 2012; van den Broeke et al., 2009). Nowhere are such changes more evident than on Greenland's fastest glacier, Jakobshavn Isbræ (Fig. 1), which sped up more than twofold over the last decade and half (Joughin et al., 2012). This speedup began in the late 1990s when Jakobshavn's Isbræ's floating ice tongue began to weaken and break up (Joughin et al., 2004; Luckman and Murray, 2005; Thomas et al., 2003), likely in response to increased basal melting (Holland et al., 2008; Motyka et al., 2011) and to weakened ice mélange in the fjord (Amundson et al., 2010; Joughin et al., 2008). Since the loss of this ice tongue, the glacier's speed has varied seasonally as its terminus advanced in winter and retreated in summer (Joughin et al., 2012). This seasonal variation of the terminus may be driven by seasonal variations in the rigidity of the ice mélange, which appear to suppress winter calving (Amundson et al., 2010). Over the past several years, the speedup has gradually increased and migrated inland due to a number of feedbacks as the glacier has thinned and retreated (Joughin et al., 2012). Largely as a consequence of this speedup, Jakobshavn Isbræ alone has contributed nearly 1 mm to global sea level over the period from 2000 to 2011 (Howat et al., 2011).

A record of Jakobshavn Isbræ's variation in speed from the mid 1990s through mid 2011 was published recently (Joughin et al., 2012). Since then, the summer speedups in 2012 and 2013 were well in excess of those observed in previous summers. Thus, here we provide a Brief Communication to extend the record of flow speed to include events through summer 2013.

2 Results

Since 2009, we have mapped regularly (approximately every 11 days) the speed of Jakobshavn Isbræ using data from the German Space Agency's (DLR) TerraSAR-X synthetic aperture radar (SAR). To do this, we applied a set of well established speckle tracking techniques (Joughin, 2002) to pairs of TerraSAR-X images separated by 11 days. Figure 2 shows a time series of speeds extracted from these velocity maps. These speeds typically have slope-dependent errors of up to $\sim 3\,\%$, which also are a function of the particular imaging geometry. Thus, the precision of the results is much better when all of the data are collected with the same viewing angle along the same orbit track (see 2009 through mid 2011 in Fig. 2) since the slope-dependent errors are the same. When a variety of imaging geometries are used, the slope-dependent errors reduce precision as is evident in Fig. 2 from mid 2011 onwards, when we started using data from multiple repeat tracks. In addition, we used a single digital elevation model (DEM) in the processing, including on the rapidly thinning ($\sim 15\,\mathrm{m\,yr^{-1}}$) trunk of Jakobshavn Isbræ. As a result, there are elevation-dependent errors of up to ~ 100 m in the geolocation accuracy of the results (i.e., the velocity is posted at the wrong location). Because these errors are geometry-dependent, the shifts are in roughly opposite directions for ascending and descending orbits, leading to relative position errors of ~ 200 m,

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which further degrade precision when comparing speeds at a point. Nonetheless, examination of speeds measured a day apart, but with different geometries, indicates that the combined sources of error rarely produce differences that exceed 3 %.

The speeds plotted in Fig. 2 are from the locations along the glacier's main trunk that are shown in Fig. 1 (M43 location not shown). The colored circles correspond to fixed points such that the name (e.g., M6) indicates the distance from the late 2003 ice front. Because these points are fixed in space, the changes in speed reflect both the influence of the terminus drawing nearer as it retreats and of the terminus retreating into deeper water. To help separate these effects, we also plotted the speed at a point (T09–T13) 1 km behind the location of where the terminus reaches its point of maximum summer retreat for the corresponding calendar year. As a result, speed at these points is largely influenced by near-terminus conditions rather than diminishing proximity to the terminus.

Figure 2 shows the change in speed on Jakobshavn Isbræ since 2009, extending a satellite-derived record that reaches back to 1992 (see Fig. S1 in Supplement) (Joughin et al., 2012). Following the near doubling of speed near the terminus in the late 1990s to early 2000s (Joughin et al., 2004; Luckman and Murray, 2005), Jakobshavn Isbræ sped up more moderately at rates of 2.6–4.4 % per year from 2004 through 2011, coincident with a strong seasonal variation in speed (Joughin et al., 2012). Our data show that in the last two years this pattern has altered, beginning with the increase in the peak summer speed at M6 by 50 % from 2011 to 2012 (11 300 to 17 000 $\mathrm{m\,yr^{-1}}$). Some of this change can be attributed to the terminus having a greater influence on speed as it moves increasing close to M6 each summer (< 1 km in 2013). Just above the terminus (orange triangles Fig. 2), peak speeds increased by 31 % from summer 2011 to 2012 (13 300 to 17 100 $\mathrm{m\,yr^{-1}}$). From 2012 to 2013, peak summer speeds near the terminus (M6 and M9) appear to have declined slightly, but increased at points farther inland (M13–M46). The TerraSAR-X satellite was inoperative for a brief period in early August 2013, so that we missed acquisitions near the time of the 2013 peak. As a result and because the peak in 2012 was brief, we can not rule out the possibility of a similarly brief peak in 2013 with a similar or even greater magnitude than 2012. The summer 2012 peak at M6 represents a 420 % increase in speed relative to the 1992, which likely had little seasonal variation (Echelmeyer and Harrison, 1990). Thus, a more direct comparison is that of the mean speed at M6 in 2012 (11 600 $\mathrm{m\,yr^{-1}}$), which yields a 1992 to 2012 speedup of 286 %.

To evaluate terminus retreat, for each TerraSAR-X image we digitized the location where the terminus intersects the white profile shown in Fig. 1 and plotted the results along the top of Fig. 2. Since there are geolocation errors associated with rapidly changing topography as described above, this yields position errors of ±100 m. While terminus position has often been correlated with terminus retreat (Howat et al., 2008), of greater importance is whether the terminus is retreating into deeper water (Howat et al., 2005; Thomas, 2004). To examine the relationship of retreat to surface and bed geometry, Fig. 3 illustrates the glacier geometry along the white profile shown in Fig. 1 along with the position of the terminus through time. We have aligned this profile to follow the deepest part of the gridded bed map, which differs from the points where we have plotted speeds.

3 Discussion

Earlier analyses indicate that depth and any height above flotation of Jakobshavn Isbræ's un-buttressed terminus exerts a strong influence on speeds within several ice thicknesses of the calving front (Joughin et al., 2012; Thomas, 2004), which also is the case for other large glaciers (Howat et al., 2005). This means that each summer as the terminus retreats into deeper water, the pressure boundary condition at the terminus produces a force that is balanced upstream by longitudinal stress gradients, which are produced through increased stretching (i.e., speedup). For example, analysis of data from 2009 indicates that the forces associated with the terminus depth variation and height above flotation account for most of Jakobshavn Isbræ's seasonal flow variation (Joughin et al., 2012). Such results are consistent with the large summer speedups in 2012 and 2013 when the terminus appears to have reached the bottom of an overdeepened basin (Fig. 3), which occurred after the terminus retreated more than a kilometer farther inland than previous summers. Additional feedbacks are likely to have contributed to the overall variation in speed as the glacier's geometry evolved in response to the additional stretching (Joughin et al., 2012; Van der Veen et al., 2011).

If Jakobshavn Isbræ's terminus has reached the bottom of an overdeepened region, then the terminus may be able to find a position of transient stability on the high spot farther upstream as retreat to shallower depths yields slower speeds. The relatively high slope region above the basin and heights of tens to hundreds of meters above flotation may further slow retreat. By contrast, low surface slopes and heights near flotation (Fig. 3) likely facilitated the rapid retreat since 2009. While the high spot above the basin may slow flow, the terminus will still be grounded on a bed at least 900 m below sea level, yielding speeds well above balance to maintain strong, although potentially diminished, thinning. As a consequence, the terminus likely will continue to retreat, albeit perhaps more slowly in the near term, until it again reaches depths similar to summers 2012 and 2013 (~ 1300 m below sea level). As the large drawdown since the 1990s indicates, this could happen over the span of a few decades or less. Once past the high spot, the trough extends roughly 50 km farther inland at depths below sea level of ~ 1200 m and greater before eventually reaching shallower depths. Thus, once into this deepest part of the trough, extreme velocities (> 16 000 $\mathrm{m\,yr^{-1}}$) are likely to persist as the terminus rapidly retreats (Thomas et al., 2011). Furthermore, without the ability to seasonally advance up a relatively steep bed slope as in the past several winters, such high speeds may be sustained year round. Because the deep trough of Jakobshavn is extremely difficult to sound (Li, 2009), we can not rule out that some or all of the high spot might be a gridding artifact, in which case retreat may occur even more rapidly.

The transient summer speeds we observe for 2012 (> 17 000 $\mathrm{m\,yr^{-1}}$) appear to represent the fastest observed speed for any outlet glacier or ice stream in Greenland or Antarctica. This yields a speed up by more than a factor of four relative to the 1990s, while the mean annual speedup is by just under a factor of 3. If, as the glacier recedes up the trough, it is able to maintain the peak speeds year round, then a sustained speedup by a factor of 4 of 5 is conceivable based on recent behavior, which is about half of the ad hoc tenfold upper limit on speed proposed by Pfeffer et al. (2008). Nevertheless, these speeds would occur in a trough roughly twice as deep as prior to the speedup. Hence, a tenfold increase in ice flux may be possible for Jakobshavn Isbræ if the trough does not narrow substantially with distance upstream. Equivalently, while the increase in terminus speed and the glaciers overall maximum speed may remain under a factor of five, as the terminus retreats farther inland where the speeds now are comparatively slow, the relative speedup is much greater (e.g., if the terminus retreated to M26 with a speed of $16\,000\,\mathrm{m\,yr^{-1}}$, this would represent a twelve-fold speedup). Thinning by hundreds of meters to a terminus near flotation, however, yields something closer to a ten-fold flux increase. It is unlikely that such retreat could be sustained for more than a few decades because the terminus would rapidly retreat $\sim 50\,\mathrm{km}$ to shallower depths (Joughin et al., 2012).

4 Conclusions

Our results show that Jakobshavn Isbræ has accelerated to speeds unprecedented in the observational record as its terminus has retreated to a depth of $\sim 1300\,\mathrm{m}$ below sea level. While the increase in discharge flux remains under a factor of three, the increase likely could reach or exceed a factor of 10 within decades. This is a consequence of the fact that retreat into deeper water increases both speed and thickness of the terminus. Conversely, where retreat to shallower depths occurs, losses will be far more moderate. Thus, the potential for large losses from Greenland is likely to be determined by the depth and inland extent of the troughs through which its outlet glaciers drain. These features are only beginning to be well resolved by international efforts such as NASA's Operation IceBridge. The relatively sparse data collected thus far indicate that with its great depths and inland extent, Jakobshavn's Isbræ is somewhat unusual (Bamber

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et al., 2013), suggesting that it may be difficult for the majority of Greenland's outlet glaciers to produce or to sustain large increases in ice discharge.

Supplementary material related to this article is available online at http://www.the-cryosphere-discuss.net/7/5461/2013/tcd-7-5461-2013-supplement.pdf.

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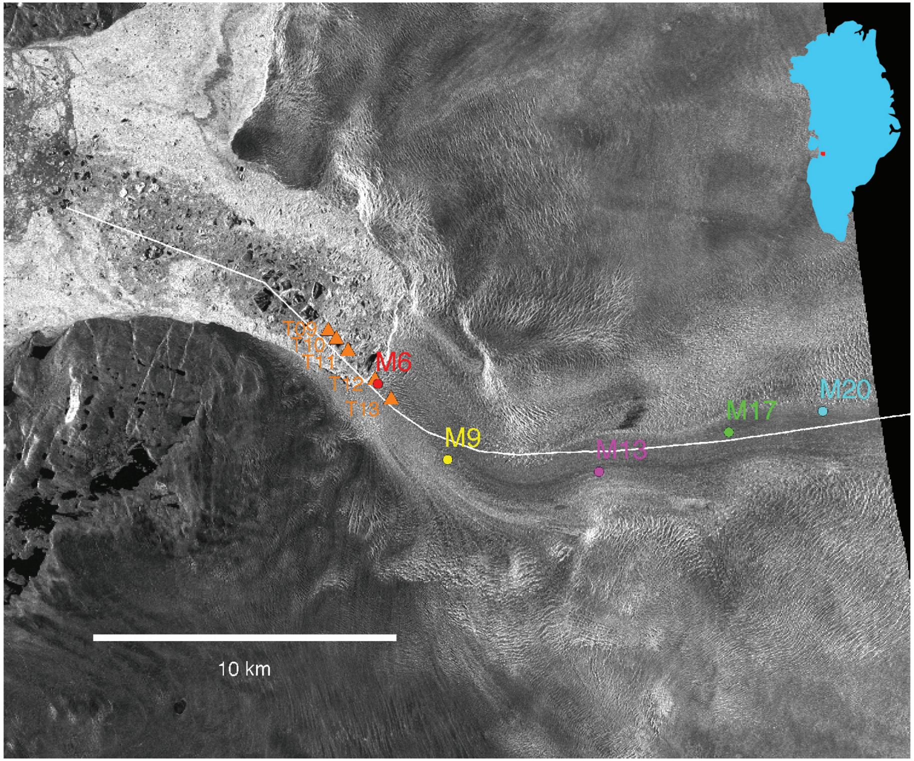

Fig. 1. TerraSAR-X image acquired 20 September when the terminus was near the point of maximum retreat in the summer of 2013. Markers M6-M20 and T09–T13 show the locations of points plotted in Fig. 2. The white profile indicates the location of the profile plotted in Fig. 3. TerraSAR-X image copyright DLR, 2013.

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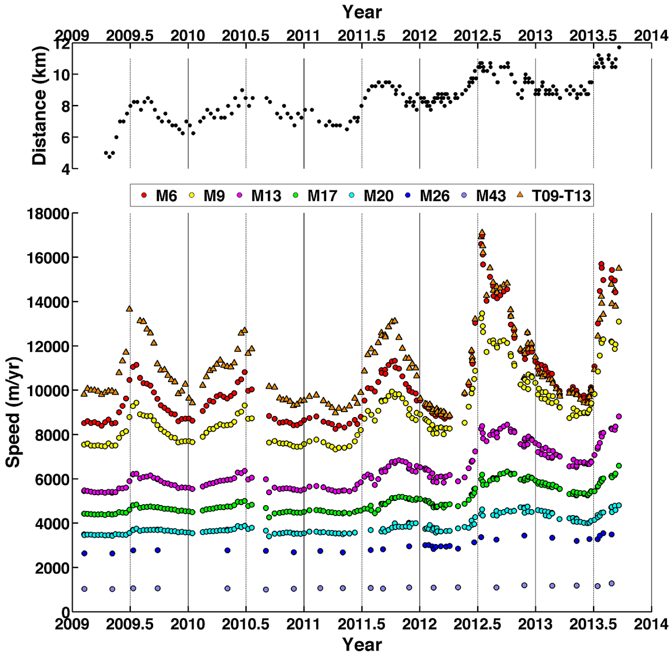

Fig. 2. Plots of (top) terminus position and (bottom) speed through time for Jakobshavn Isbræ determined from TerraSAR-X data collected from 2009 to 2013. Terminus position was digitized where it intersects the white profile shown in Fig. 1. The color circles (M6–M43) show the speed at several points along the glacier's main trunk at the locations shown in Fig. 1 (M43 location not shown; Joughin et al., 2008). Each point's numerical designation (e.g., M6) gives the approximate distance in kilometres from glacier terminus in late summer 2003 and these points are used for consistency with earlier records (Joughin et al., 2008, 2012). Additional markers, T09–T13 (orange triangles) (locations shown in Fig. 1), are each situated 1 km upstream of the terminus at its position of maximum retreat for the years 2009–2013. Each year, speeds are plotted for the corresponding point (T09–T13).

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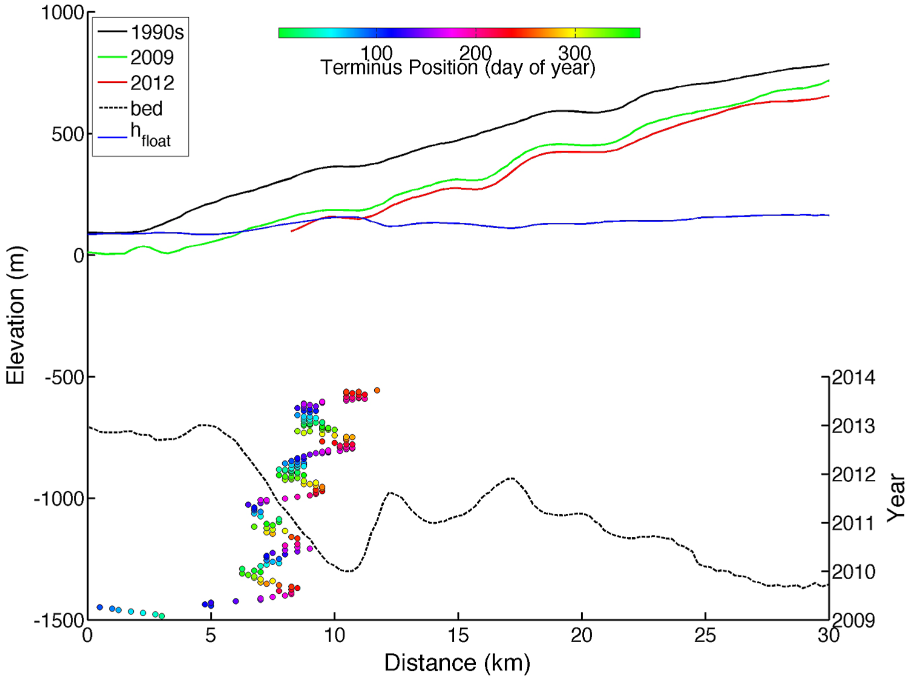

Fig. 3. Surface and bed elevations in the near-terminus region of Jakobshavn Isbræ along the profile shown in Fig. 1. Terminus position (x axis) is shown as a function of time (right y axis) with color to indicate day of year. Surface elevations were determined by interpolating data collected by NASA's Airborne Topographic Mapper (ATM) in the 1990s, 2009, and 2012 as part of Operation Icebridge and its predecessor missions (Krabill et al., 2004). Bed elevations were interpolated from a gridded map of radar depth soundings produced by the Center for Remote Sensing of Ice Sheets (CReSIS) (Li, 2009; Van der Veen et al., 2011). Multiple versions of the DEM exist, but based on comparison with other data sets our preferred version is the one located at (ftp://data.cresis.ku.edu/data/grids/old_format/2008_Jakobshavn.zip).