Seasonal velocity variations of 12 outlet glaciers from the Greenland ice sheet derived from *in situ* GPS instruments

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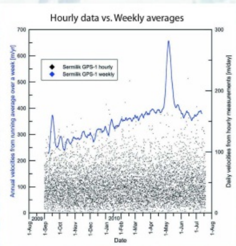
Abstract

We present 34 velocity records derived from in situ stand-alone single-frequency Global Positioning System (GPS) receivers placed on 12 marine-terminating ice sheet outlet glaciers in South, West, East and North Greenland, covering varying parts of the period summer 2009 to spring 2013.

Common to most the observed glacier velocity records is a pronounced seasonal variation, with an early melt season maximum. The GPS-derived velocities are compared to velocities derived from radar satellite imagery over six of the glaciers to illustrate the potential of the GPS data for validation purposes. Three different velocity map products are evaluated, based on ALOS/PALSAR data, TerraSAR-X/Tandem-X data and an aggregate winter TerraSAR-X data set. The velocity maps derived from TerraSAR-X/Tandem-X data have a mean difference of 1.5% compared to the mean GPS velocity over the corresponding period, while velocity maps derived from ALOS/PALSAR data have a mean difference of 9.7%. The velocity maps derived from the aggregate winter TerraSAR-X data set have a mean difference of 9.5% to the corresponding GPS velocities. The data are available from the GEUS repository at http://dx.doi.org/10.5280/GEUS000001.



The Problem

- Dynamic mass loss from calving outlet glaciers still poorly understood
- Modelling calving outlet glaciers requires observational data
- In situ observations provide the detailed seasonal variation in outlet glacier velocity

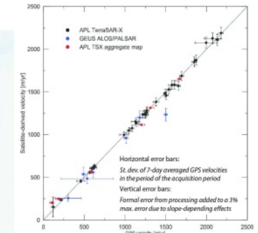
The Instruments

- stand-alone GPS receiver from IMAU and Dr. A.Behar, respectively
- single-frequency (L1 band) system for extended operation in harsh conditions with no maintenance at a low instrument cost
- Behar-GPS: 15 D cell Li-SOCl2 3.6V batteries >two years (67.5 Ah)
- Ice2sea GPS: 3.6V lithium battery >one year at 15 Ah/yr only time and position stored in data logger - no post-processing possible estimated error of a single measurement is *c.* 3-4 metres

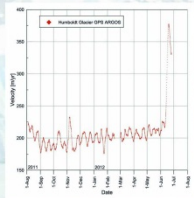
Summary

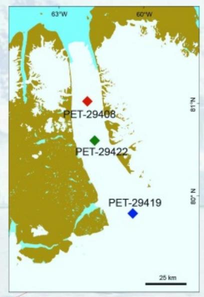
The 34 continuous in situ GPS velocity records presented here were acquired on 12 marine-terminating outlet glciers from the Greenland ice sheet, spanning various parts of 2009-2013 and representing a variety of glacier types

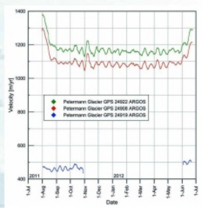
- A common feature is a pronounced seasonal variation in velocity, with an early melt season maximum, often followed by a late summer minimum
- Generally, the onset of the acceleration comes later for northern glaciers.
- Each individual glacier tends to reproduce its own pattern of seasonal velocity variation.
- The GPS records are useful as ground-truthing velocity mapping from satellite data, but also for determining how well the velocity maps represent the periods outside the image acquisition windows.
- The GPS velocity records support modeling efforts investigating the coupling between the ice sheet and the ocean/climate and thus serve to improve our understanding of the dynamic mass loss from the Greenland ice

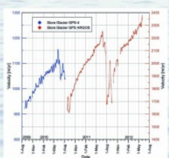


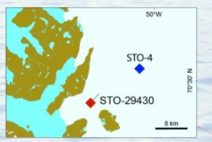
The GPS velocities compare well with a variety of satellite-derived velocity maps, supporting the validity of the velocity mapping technique, even over fast-flowing outlet glaciers. The comparison improves with higher resolution and shorter time span, suggesting that the in situ GPS data presented are indeed useful for ground-truthing the satellite products, despite being single-frequency stand-alone instruments.

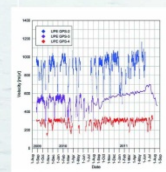


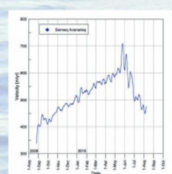


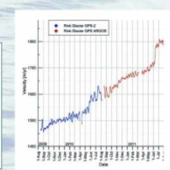


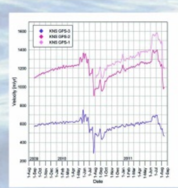


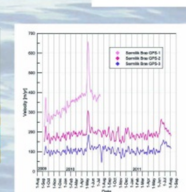












The Processing

The raw IMAU data consists of hourly (or every third hour in the case of ARGOS transmitted data) measurements of time and geographical position, whereas the Behar-GPS's transmit every 12 hours. In the case of the raw hourly IMAU data, outliers are removed by comparing consecutive standard deviations of the latitudinal and longitudinal positions over a moving time window of 60 h. If the difference between consecutive standard deviations is larger than a threshold of 0.2 m, the record is excluded from further analysis running average (modified Welch) applied to the latitudinal and longitudinal position, respectively, over a 7-day period (168 h). Average positions are calculated if more than 95% of the records within a given time window is present application of a similar 7-day running average to the velocities derived from the averaged positions

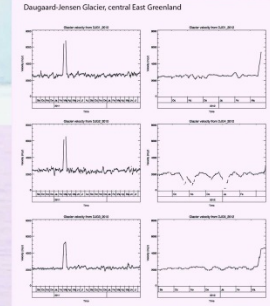
The 12-hour data had outliers removed based on comparison to the st.dev. of the entire record, before boxcar averaging over a 7-day interval (c. 15 measurements) over both positions and velocities.

The Greenland data yield a typical error of 5 m/yr, if 7-day running averages are considered.
This 5 m/yr is the standard deviation used in this study.

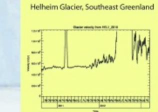
Due to spurious waves and spectral leakage caused by the averaging procedure we only consider periodic fluctuations with amplitude over 30 m/yr.

The new data - fresh off the instrument

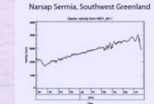
Daugaard-Jensen Glacier, central East Greenland



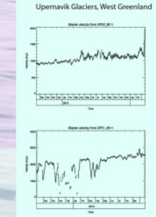
Helheim Glacier, Southeast Greenland



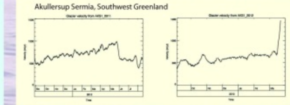
Narsap Sermia, Southwest Greenland



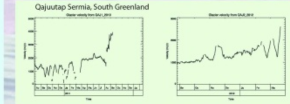
Upernavik Glaciers, West Greenland



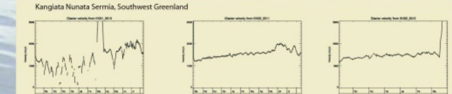
Akullersup Sermia, Southwest Greenland



Qajuutap Sermia, South Greenland



Kangiata Nunata Sermia, Southwest Greenland



Acknowledgements

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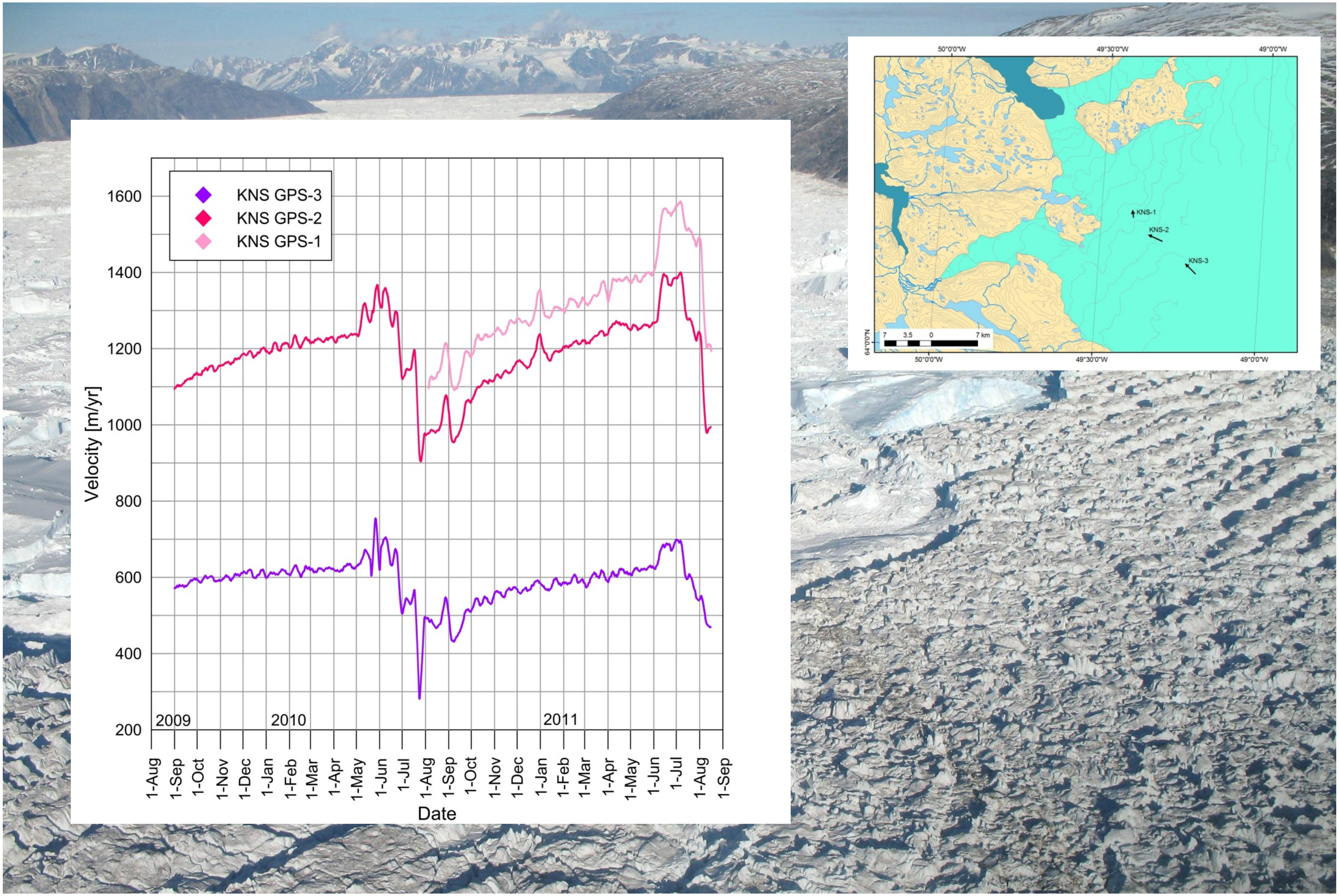
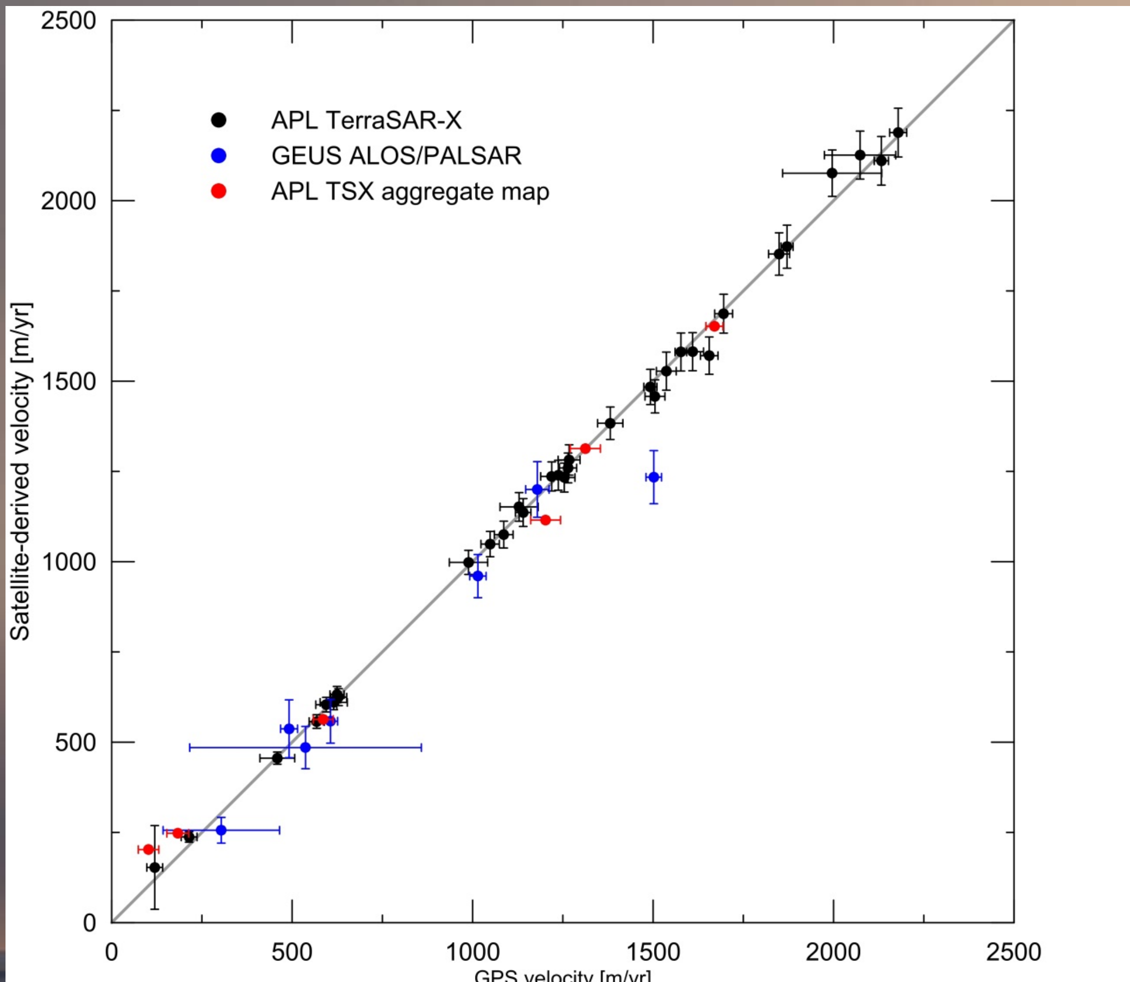
Sample: Velocity of KNS in Southeast Greenland



One use: Satellite-derived velocities vs. GPS velocities



<u>Horizontal error bars:</u>
St. dev. of 7-day averaged GPS velocities in the period of the acquisition window

<u>Vertical error bars:</u>
Formal error from processing added to a 3% max. error due to slope-depending effects