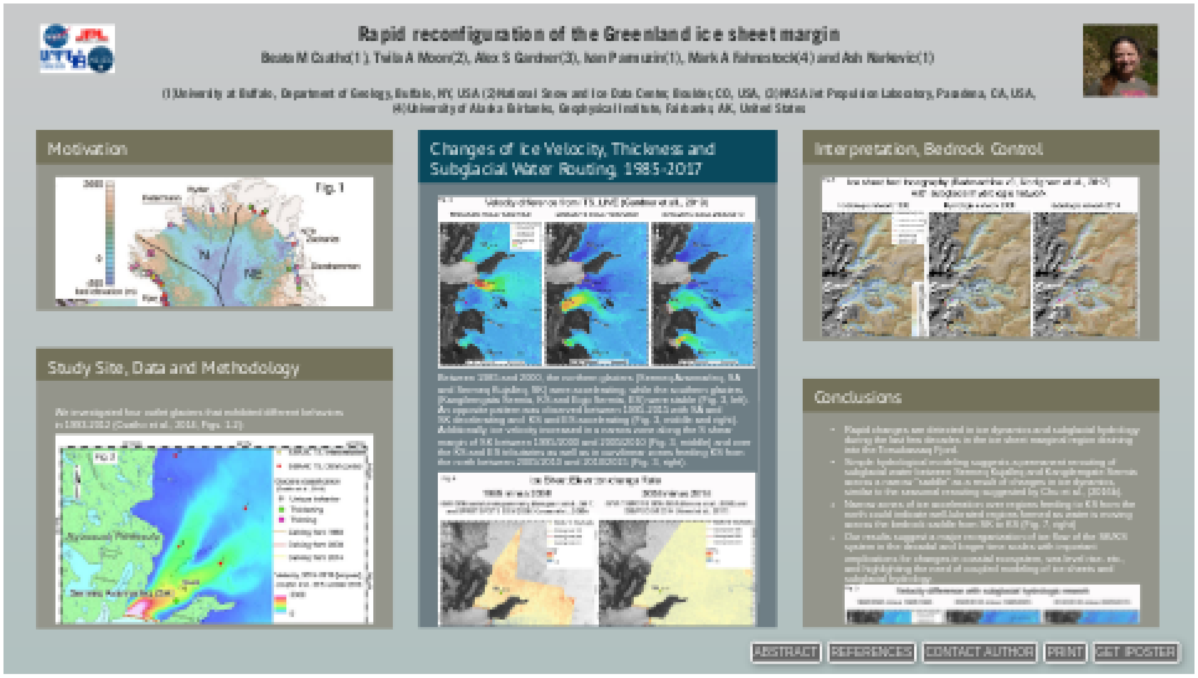
Rapid reconfiguration of the Greenland ice sheet margin



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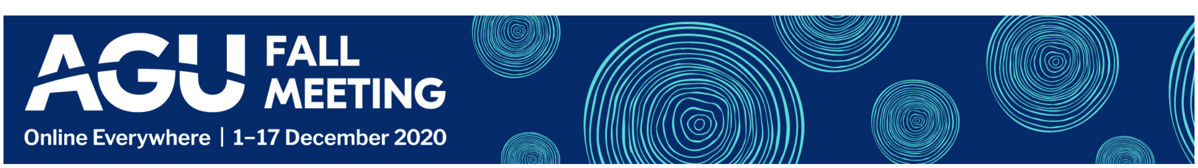


MOTIVATION

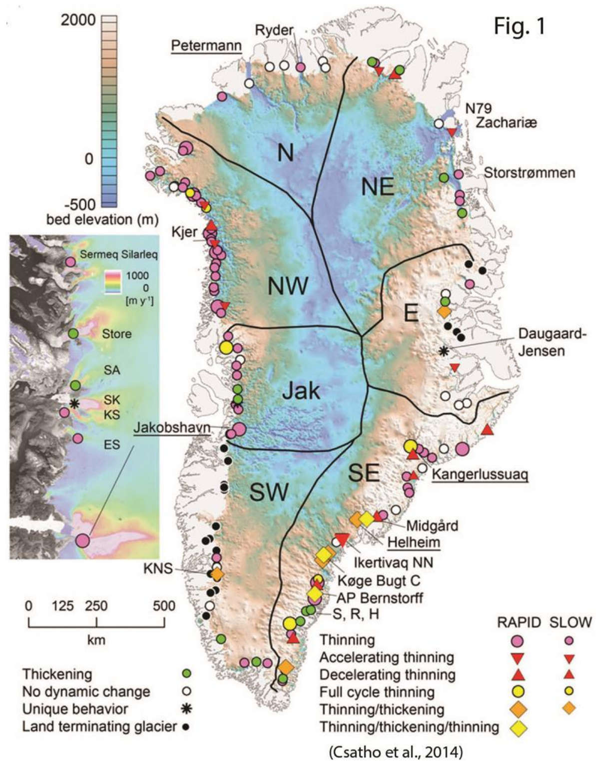
The eemote sensing record reveals continuing dynamic thinning providing a substantial contribution to the mass loss of the Greenland Ice Sheet (Shepherd et al., 2020).

Although the rapid acceleration of Greenland Ice Sheet mass loss during the last few decades is well documented, less attention was given to the local reorganization of ice flow and its consequences.

The large spatiotemporal variations of outlet glacier dynamic mass loss (Fig. 1 from Csatho et al., 2014) and widespread intermittent thinning indicate the complexity of ice sheet response to climate forcing.

Moreover, ice sheet reconfiguration is observed in decadal time scales, expressed as narrowing zones of fast-flow, ice flow rerouting, shear margin migration, and potential glacier abandonment (Moon et al., 2020).

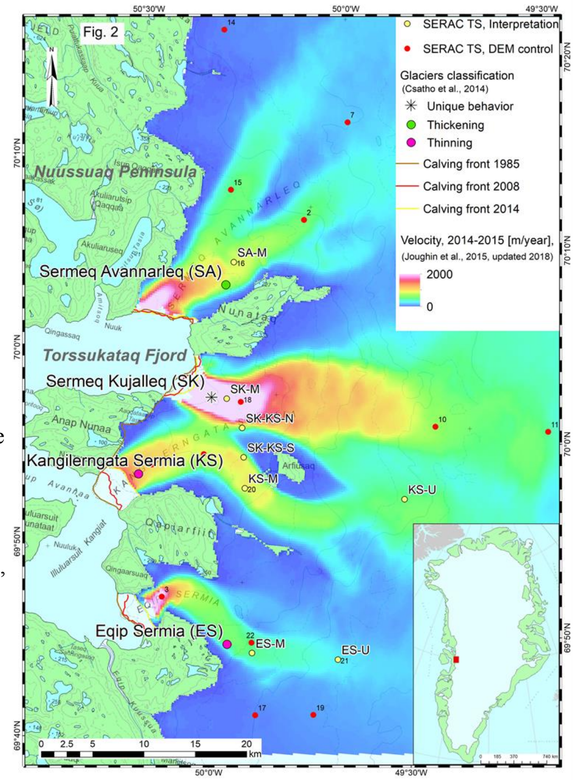
This study examines the remote sensing record of the glaciers draining into the Torssukatak Fjord in central West Greenland to identify the reason for their different decadal-scale behaviors (Fig. 1, left inset).



STUDY SITE, DATA AND METHODOLOGY

We investigated four outlet glaciers that exhibited different behaviors in 1993-2012 (Csatho et al., 2014, Figs. 1-2):

- Sermeq Avannarleq (SA), dynamic thickening,
- Sermeq Kujallek (SK), unique behavior, including a rapid switch from thinning to thickening,
- Kangilerngate Sermia (KS), dynamic thinning,
- Eqip Sermia (ES), dynamic thinning.



Data sets:

- Digital Elevation Models from stereo aerial photographs (1985, Korsgaard et al., 2016), SPIRIT SPOT 5 satellite imagery (2008, Korona et al., 2009) and DigitalGlobe/GeoEye high-resolution commercial satellite imagery (2014, Howat et al., 2017),
- Ice sheet velocity from ITS_LIVE (Inter-Mission Time Series of Land Ice Velocity and Elevation (1985-2015, Gardner et al., 2019),
- Airborne (ATM, LVIS) and spaceborne (ICESat) laser altimetry data (1997-2017, Studinger, 2014; Blair and Hofton, 2019; Zwally et al., 2014),
- BedMachine V3 bedrock DEM (Morlighem et al., 2017).

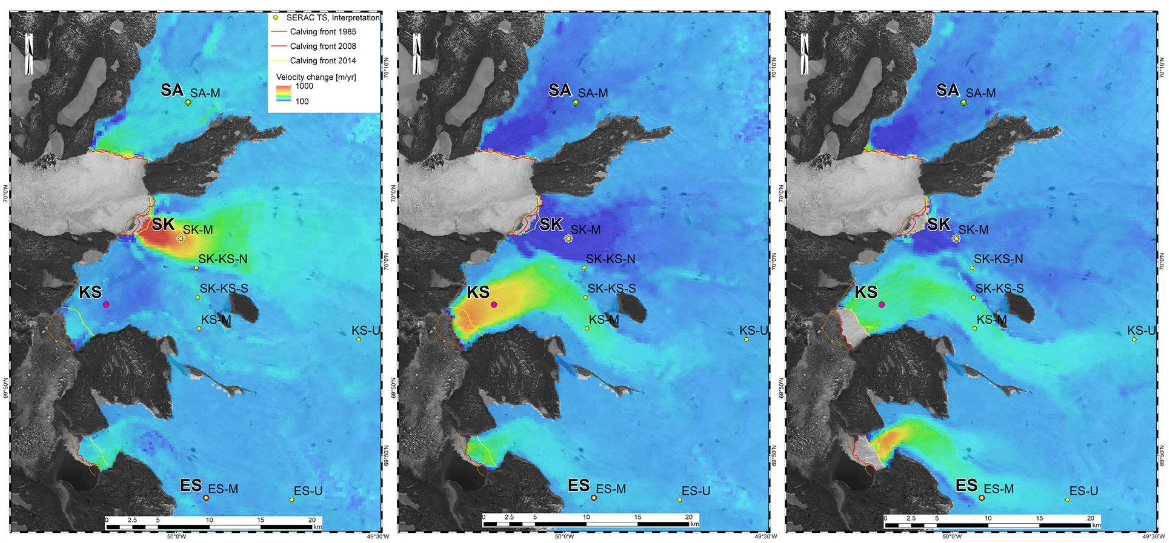
Methodology:

- Ice velocity changes were computed by differencing pentad data,
- Ice thickness changes were computed by differencing surface DEMs. DEM accuracy is assessed by SERAC altimetry time series (red circles),
- Potential subglacial hydrologic networks were reconstructed from surface and bed DEMs (Lewis and Smith, 2009; Chu et al., 2016a),
- Ice sheet elevation change time series were reconstructed and partitioned into changes due to surface processes and ice dynamics generated from airborne (ATM, LVIS) and spaceborne (ICESat) laser altimetry data using the Surface Elevation Reconstruction And Change detection (SERAC) method (Csatho et al., 2014) (yellow circles).

CHANGES OF ICE VELOCITY, THICKNESS AND SUBGLACIAL WATER ROUTING, 1985-2017

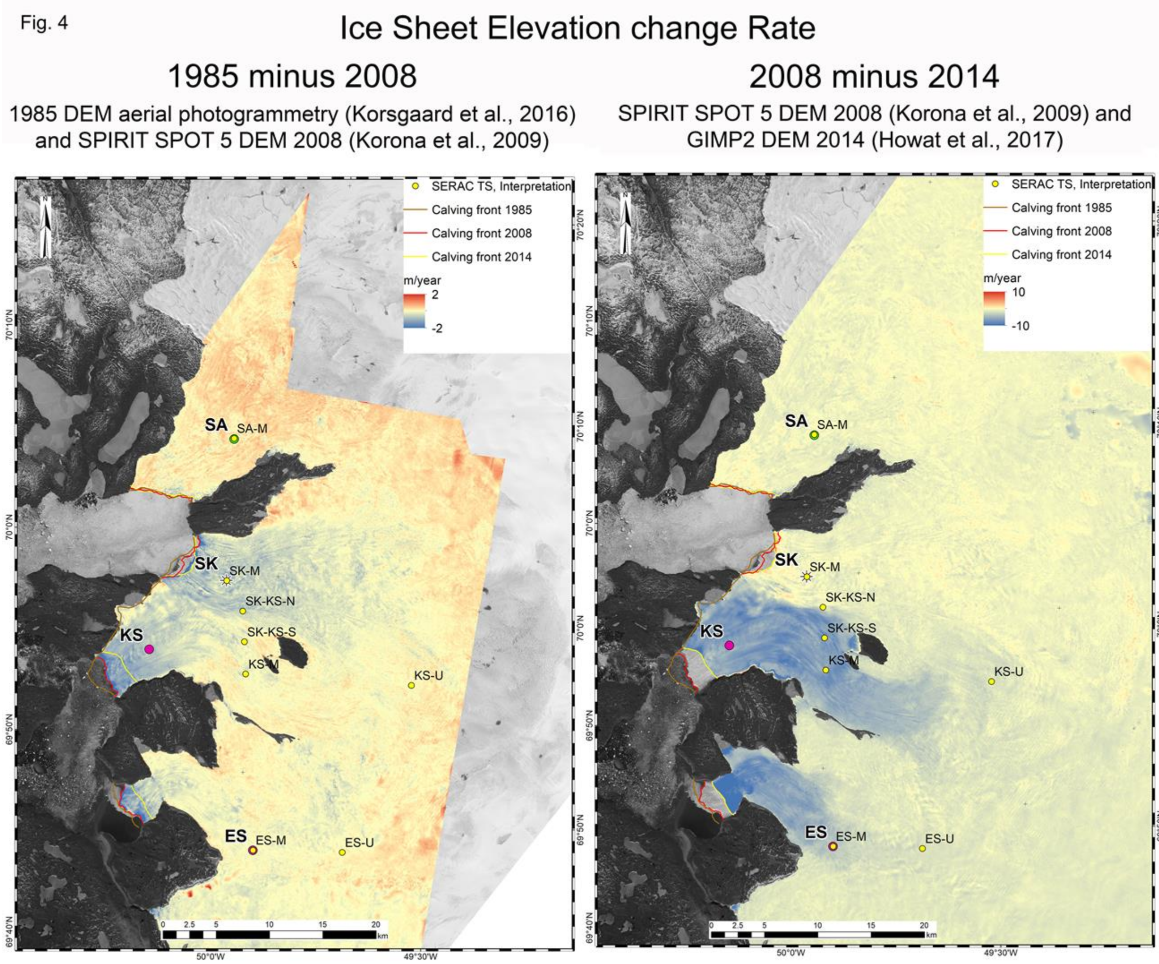
Fig. 3 Velocity difference from ITS_LIVE (Gardner et all., 2019)

1995/2000 minus 1985/1990 | 2005/2010 minus 1995/2000 | 2010/2015 minus 2005/2010



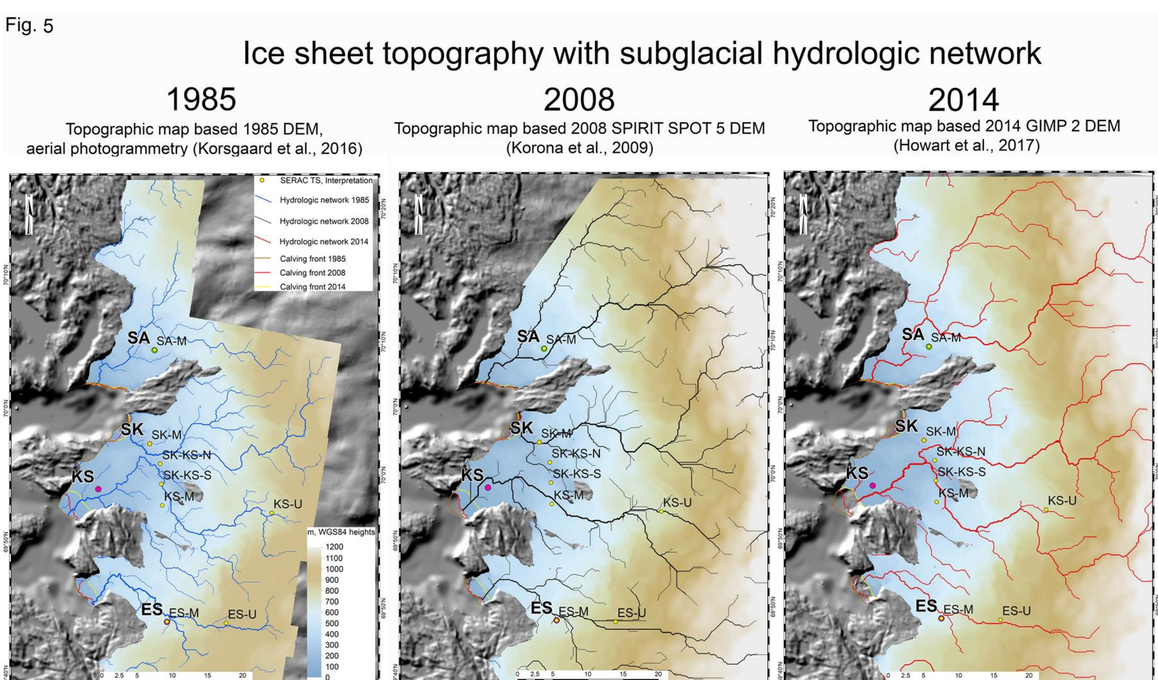
Between 1985 and 2000, the northern glaciers (Sermeq Avannarleq, SA and Sermeq Kujalleq, SK) were accelerating, while the southern glaciers (Kangilerngata Sermia, KS and Eqip Sermia, ES) were stable (Fig. 3, left). An opposite pattern was observed between 1995-2015 with SA and SK decelerating and KS and ES accelerating (Fig. 3, middle and right). Additionally, ice velocity increased in a narrow zone along the S shear margin of SK between 1995/2000 and 2005/2010 (Fig. 3, middle) and over the KS and ES tributaries as well as in curvilinear zones feeding KS from the north between 2005/2010 and 2010/2015 (Fig. 3, right).

Fig. 4



The 1985-2000 speed-up of SK and the 1995-2010 speed-up of KS resulted in thinning of these glaciers between 1985 and 2008, while, at the same time, SA was slightly thickening, probably due to its slow-down oberserved after 2000 (Fig. 4, left). Between 2008 and 2014 KS and ES exhibited rapid thinning (Fig. 4, right) as they accelerated after 2000 (Fig. 3). Note the more extensive inland thinning and acceleration of KS compared to ES (Figs. 3-4).

Fig. 5



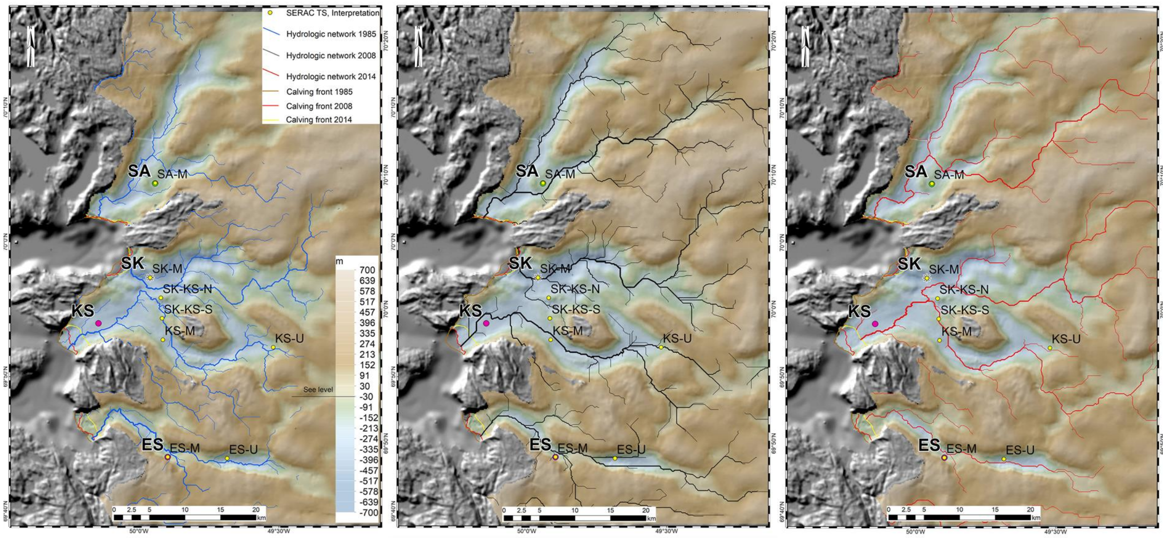
The evolution of the subglacial network indicates that changes in ice sheet surface topography from marginal thinning caused a rerouting of subglacial water between Sermeq Kujallek (SK) and Kangilerngata Sermia (KS). In 1985 SK might have received subglacial water from KS, resulting in rapid thinning during a period of stable terminus position (Fig. 3, left). However, by 2014, KS appeared to capture most of the subglacial water from SK, causing widespread and extensive speed-up and thinning (Fig. 3, right and Fig. 4, right).

INTERPRETATION, BEDROCK CONTROL

Fig. 6

Ice sheet bed topography (Bedmachine v3, Morlighem et al., 2017) with subglacial hydrologic network

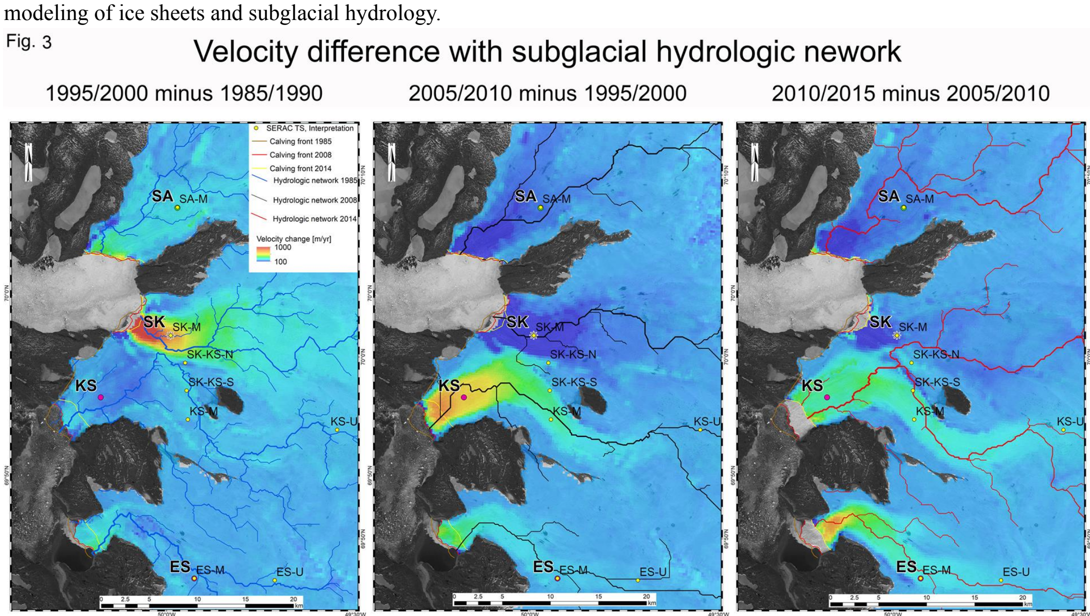
Hydrologic network 1985 | Hydrologic network 2008 | Hydrologic network 2014



- The terminus regions of Sermeq Kujallek and Kangilerngata Sermia are separated by a low "saddle" in the bedrock topography with bed elevations below sea level.
- This region facilitated the permanent rerouting of subglacial water as coastal thinning altered the ice sheet topography.
- We interpret the stability of Sermeq Kujalleq and the rapid thinning of Kangilerngata Sermia after 2000 as a result of this subglacial rerouting.
- The shape of the sills under the glaciers termini appear to control their dynamic behavior (An et al., 2018), with sills that are only breached by narrow channels, such as the terminus of SA, resulting in stable behavior and dynamic thickening.
- While SK terminates on a bedrock sill, KS has a wide, U-shape channel, indicating that KS might have been the long-term outlet of ice flow from the SK/KS system.

CONCLUSIONS

- Rapid changes are detected in ice dynamics and subglacial hydrology during the last few decades in the ice sheet marginal region draining into the Torsukassaq Fjord.
- Simple hydrological modeling suggests a permanent rerouting of subglacial water between Sermeq Kujalleq and Kangilerngate Sermia across a narrow "saddle" as a result of changes in ice dynamics, similar to the seasonal rerouting suggested by Chu et al., (2016b).
- Narrow zones of ice acceleration over regions feeding to KS from the north could indicate well-lubrated regions formed as water is moving across the bedrock saddle from SK to KS (Fig. 7, right)
- Our results suggest a major reorganization of ice flow of the SK/KS system in the decadal and longer time scales with important omplications for changes in coastal ecosystem, sea level rise. etc., and highlighting the need of coupled modeling of ice sheets and subglacial hydrology.



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ABSTRACT

The rapid acceleration of Greenland Ice Sheet mass loss over, particularly the last two decades, is well documented. However, limits in early remote sensing restricted the details with which we could examine local changes on an ice-sheet-wide scale, particularly in areas of slow motion, along shear margins and complex coastal terrain. We explore the local character of rapid contemporary change marine-terminating glaciers using satellite-derived ice sheet surface velocities, glacier terminus advance/retreat history, and surface elevation-change data from the 1980s to the present. Widespread glacier terminus retreat is a strong and more consistent climate response indicator than velocity change, but local changes in velocity are critical indicators of rapid ice sheet reconfiguration. Ice thickness changes related to changing ice dynamics often provide the first evidence of processes that initiate outlet glacier retreats and mass loss, such as the development of sub-ice shelf cavities and subglacial hydrology changes. Reconfiguration is observed locally as narrowing zones of fast-flow, ice flow rerouting, shear margin migration, and likely glacier outlet abandonment. These patterns are apparent in all ice sheet sectors and observable from space-borne instruments. The rapid reconfiguration now well underway in Greenland has wide-ranging implications, including expected changes in subglacial hydrology, ice discharge, freshwater flux to the ocean, and transport of nutrients and sediment. Lacking detailed observations of earlier deglaciations and current limits on ice-sheet model capabilities, the expanding details of these combined observational records may provide a valuable analog for studying past ice sheet dynamics and projecting future ice loss.

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