Patterns of (marine-terminating) glacier variability in Greenland

Twila Moon

Earth & Space Sciences, University of Washington

Polar Science Center, Applied Physics Lab, University of Washington

Collaborators:

Ian Joughin[1], Ben Smith[1], Ian Howat[2]

[1] *Polar Science Center, Applied Physics Lab, University of Washington*

[2] *Byrd Polar Research Center, Ohio State University*

- **Remote sensing of velocity and terminus position**

- **Ice-shelf—terminating glaciers**

    - Concentrated in northern Greenland, mixed signals of change

- **Annual and multi-year velocity variability**

    - Regional and local variability within large-scale speedup

- **Interannual terminus change**

    - Regional and local patterns of advance/retreat are not synchronous, despite overall retreat

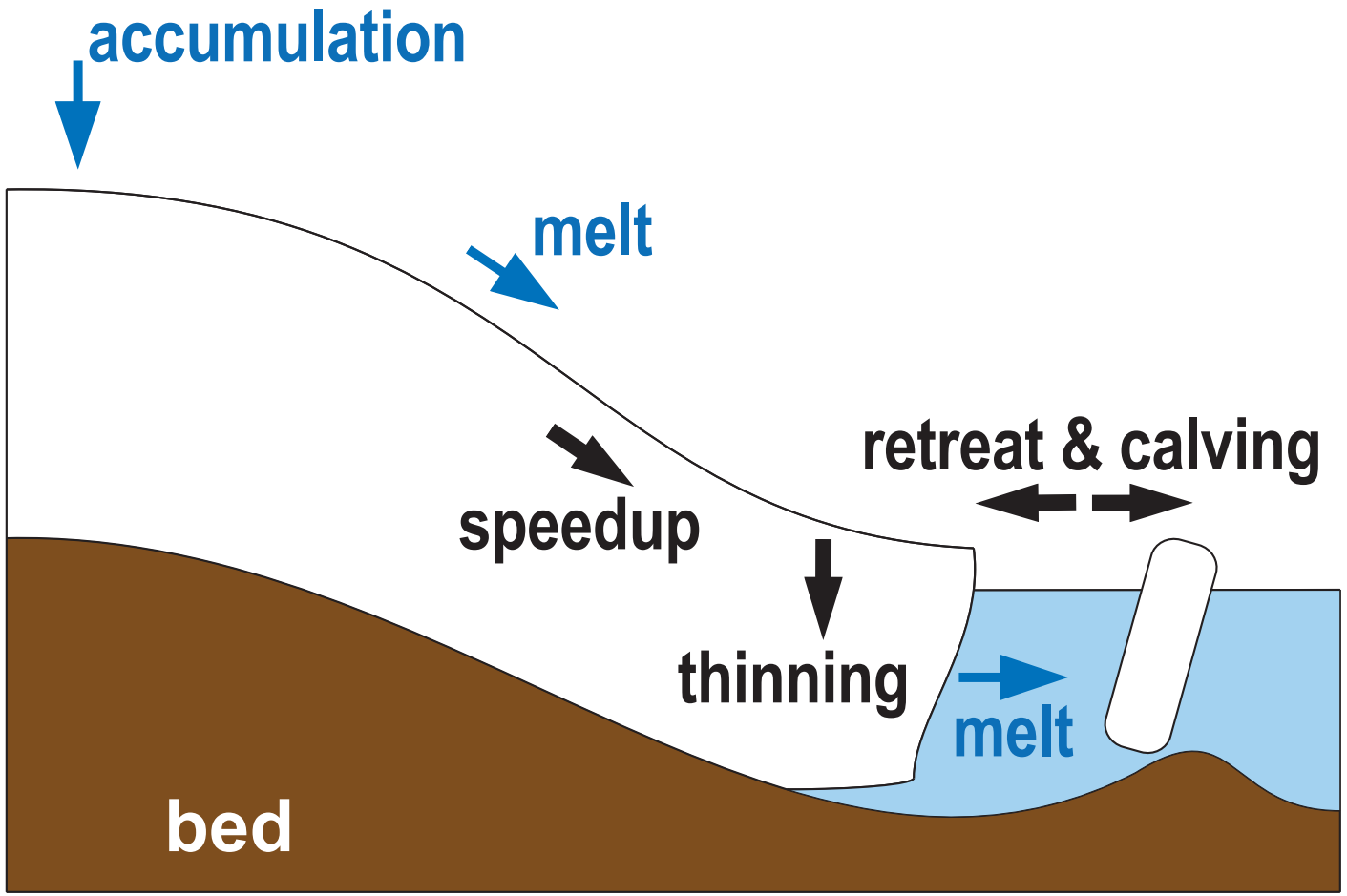
- **What next?**

    - Understand the system on multiple scales (time & space) and identify associated mechanisms and predictive relationships

    - Determine how observation and prediction should move forward together

*Surface mass balance components

*Ice discharge components

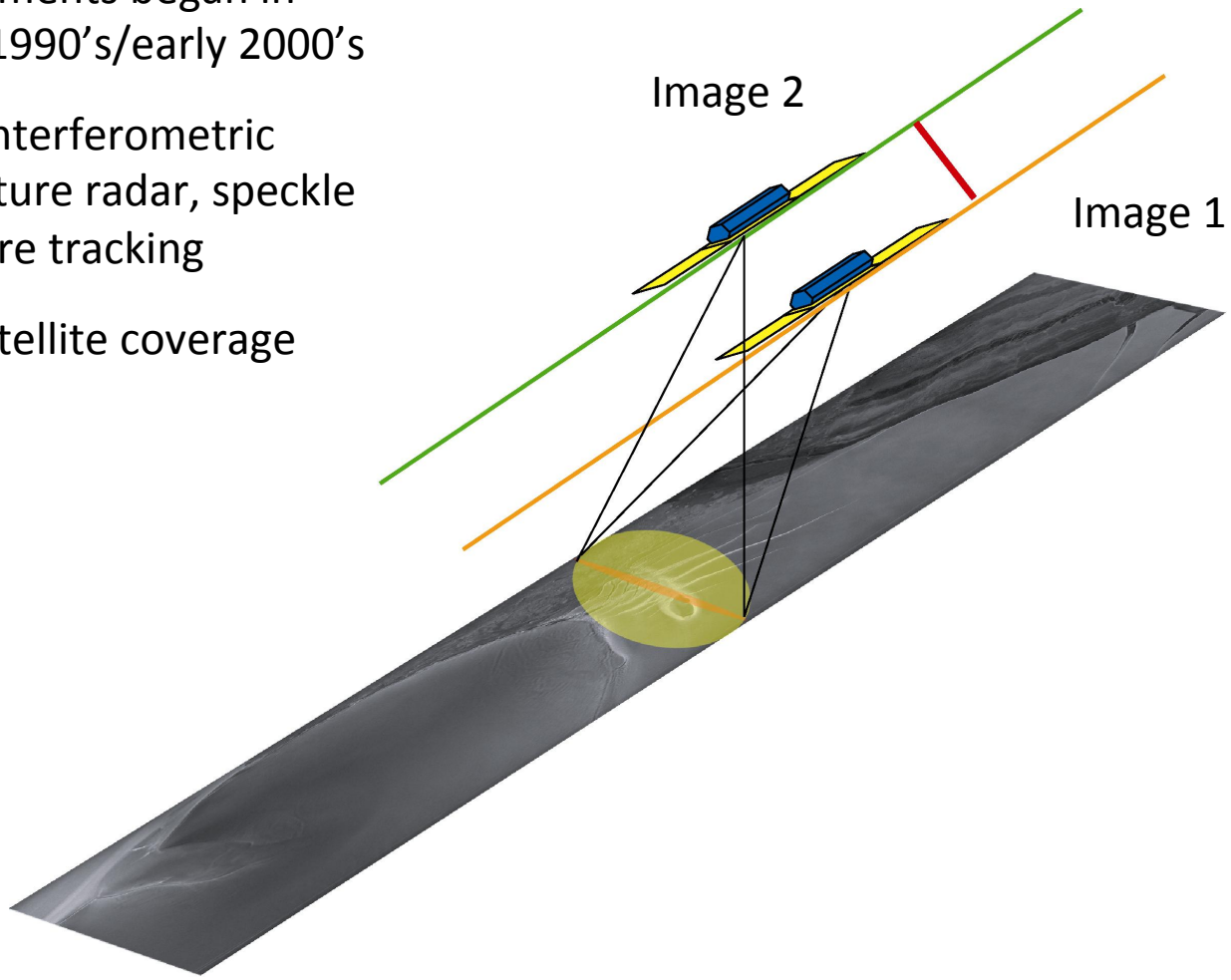


Measurements via remote sensing

- **Velocity** measurements began in earnest in the late 1990's/early 2000's

  -Techniques: Interferometric synthetic aperture radar, speckle tracking, feature tracking

  - Limited by satellite coverage



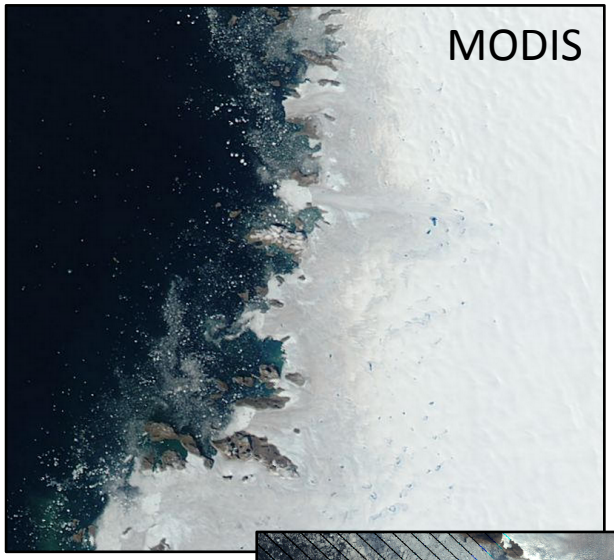
[Graphic: I. Joughin]

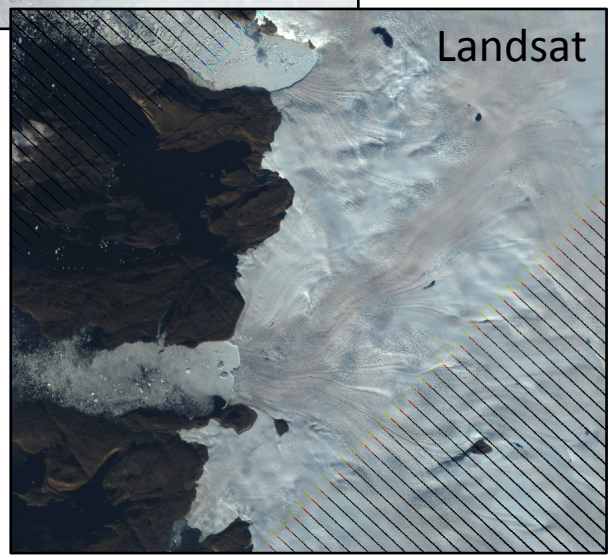
Measurements via remote sensing

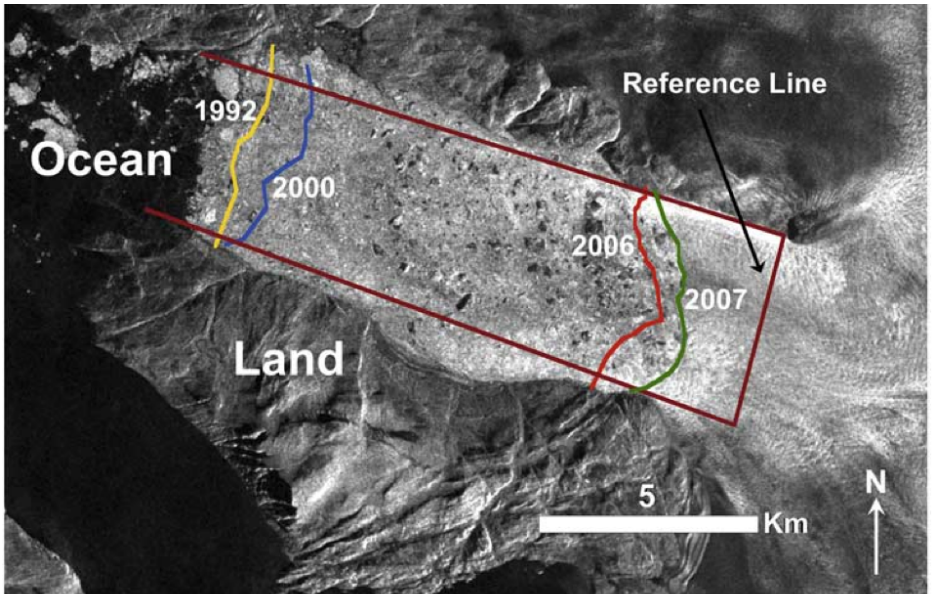
-**Advance/Retreat** measurements take advantage of a range of imagery (Landsat, MODIS, TerraSAR-X, etc.) with resolution ~15-250 m/pixel

-Techniques: centerline measurements, box method, reference-point measurements

- Limited by coverage and atmospheric conditions

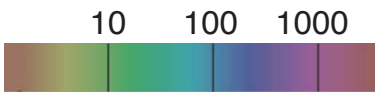


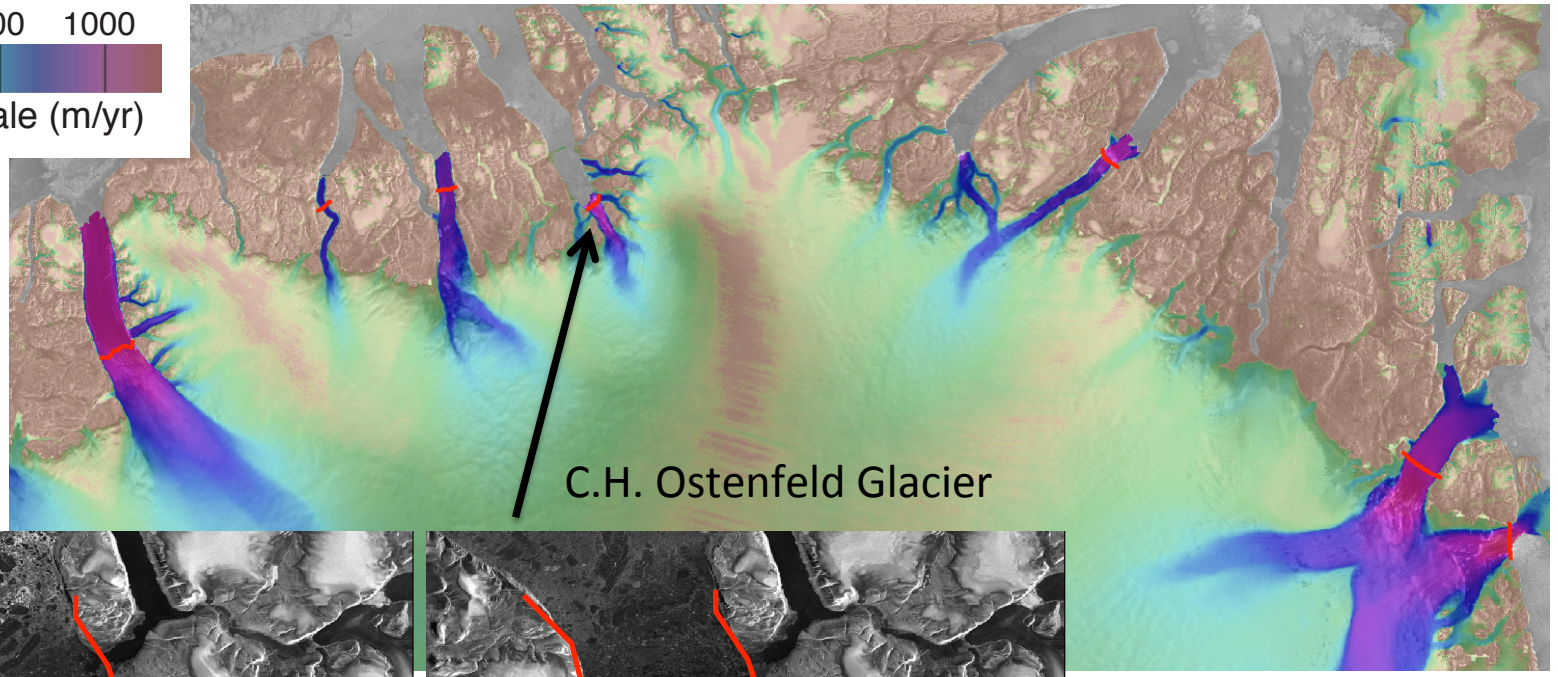


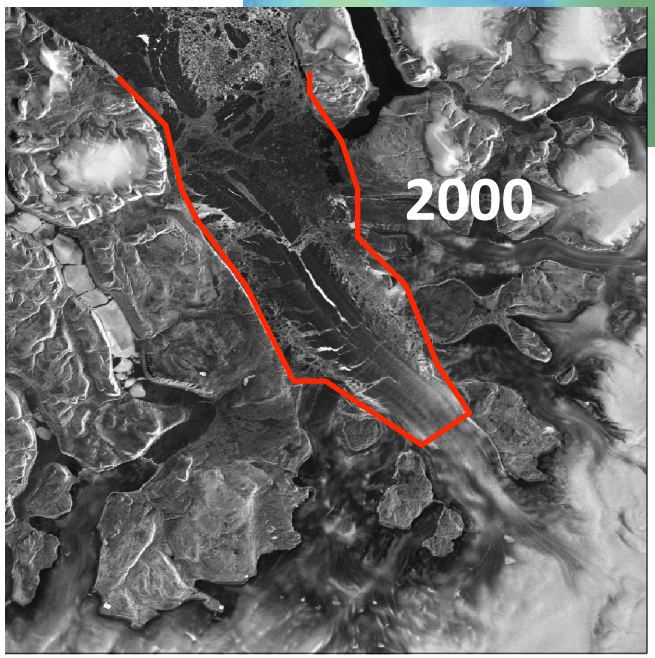


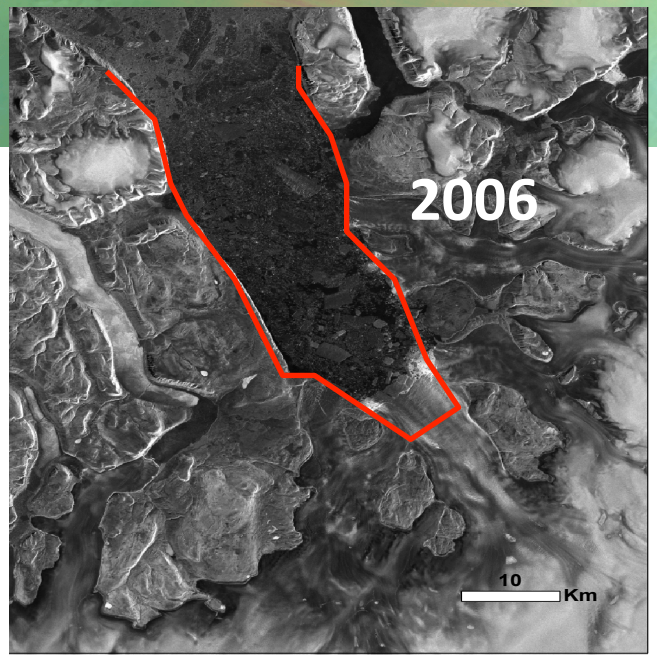
[Moon & Joughin, 2008]

Changes on glaciers with floating ice tongues









[Grounding lines from:
Rignot et al., 2001]

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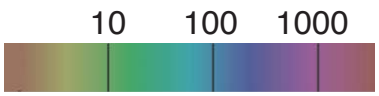

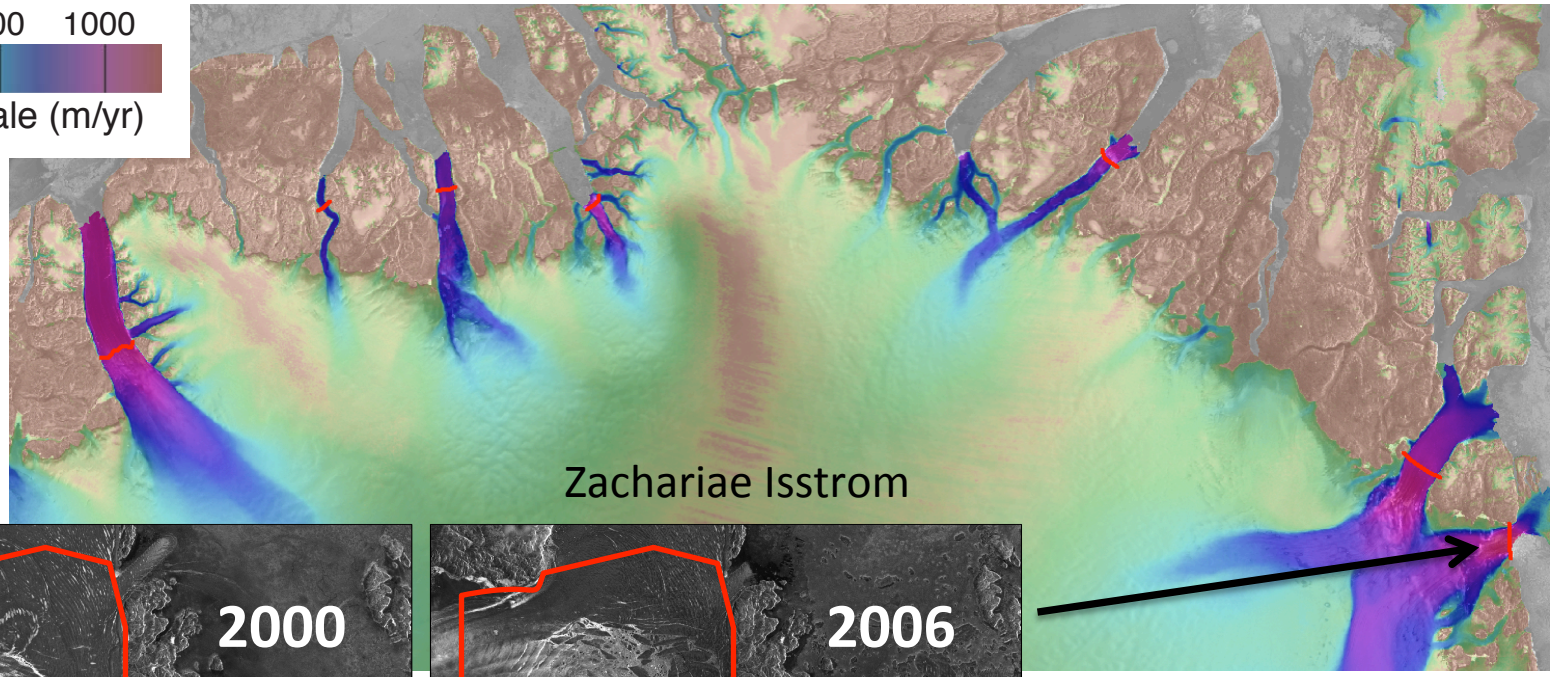

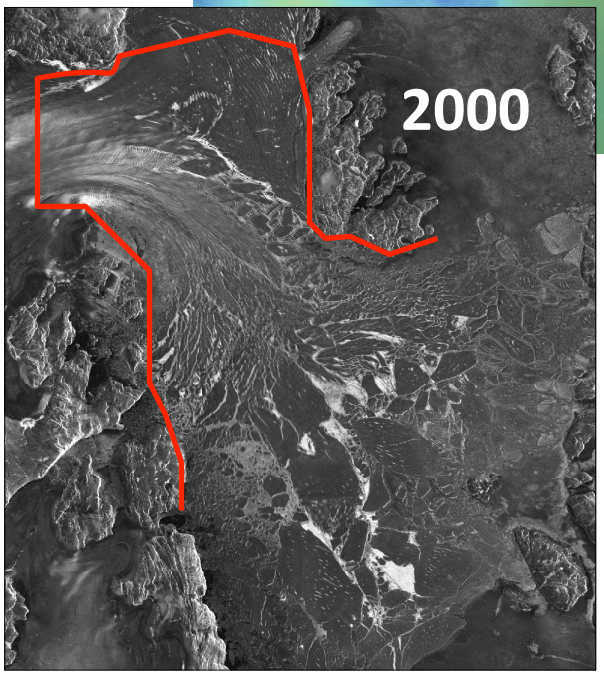

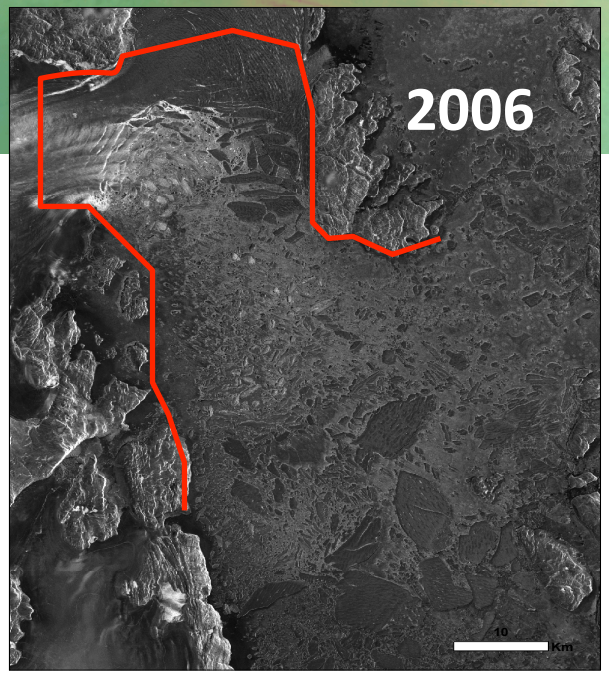

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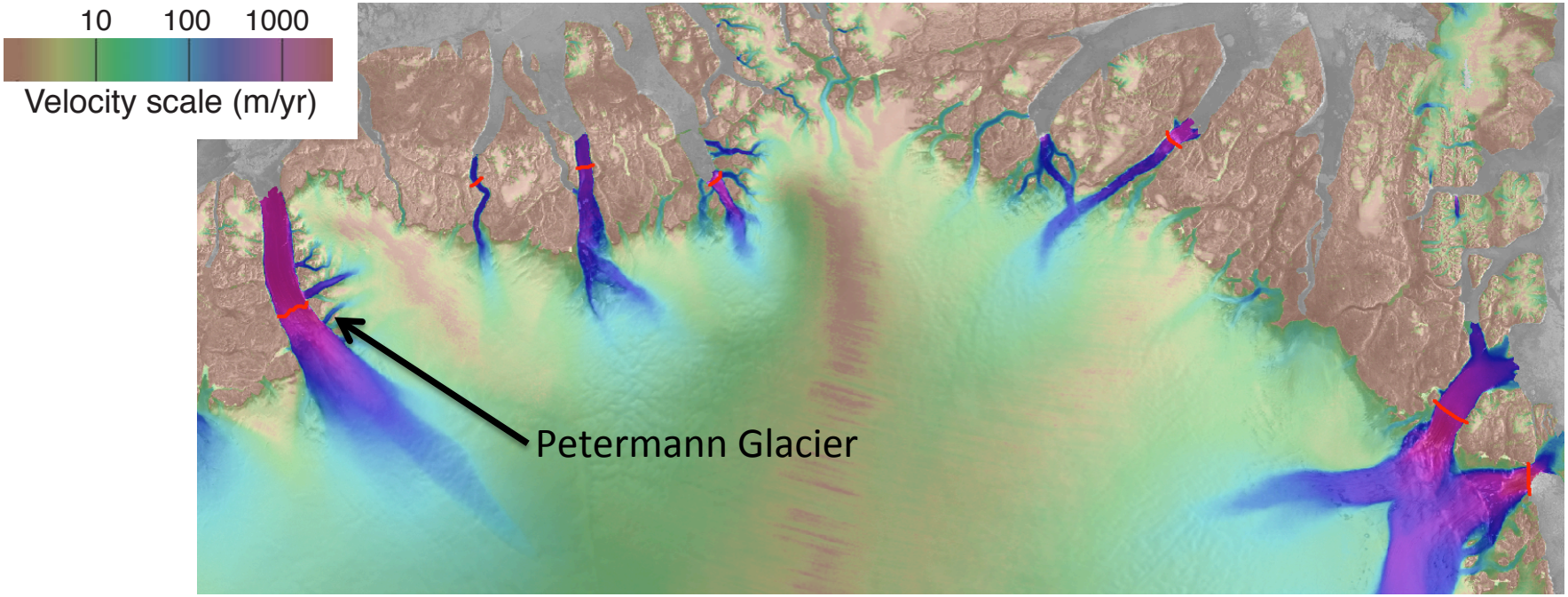
Changes on glaciers with floating ice tongues

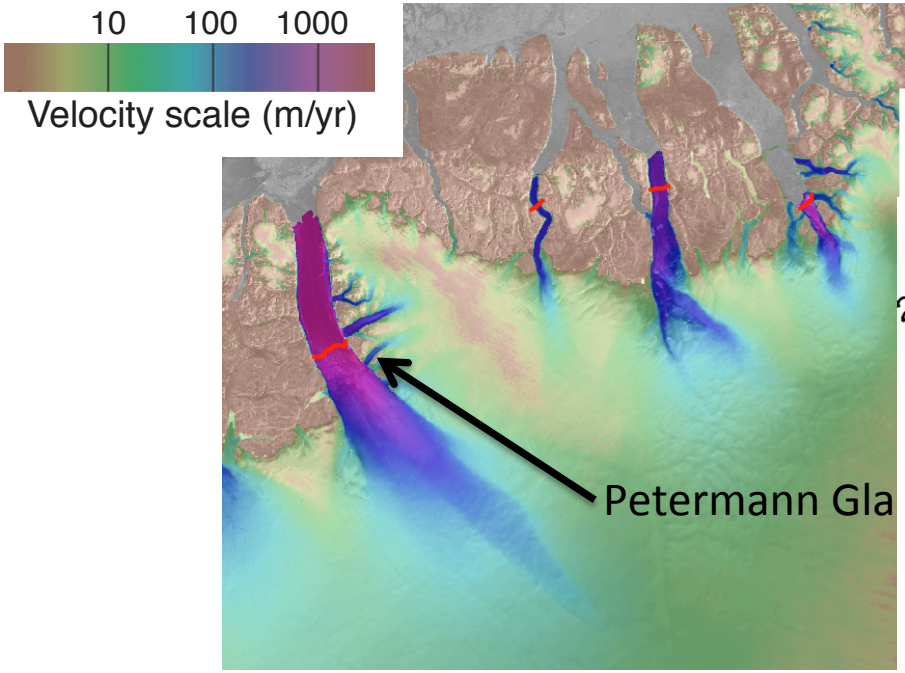


- Notable changes in front position, including apparent complete loss of floating ice in the last 1-2 decades [e.g., Box & Decker 2011]

- During 2000-2010, these northern ice-shelf terminating glaciers had a negligible change in winter-to-winter velocity

[Grounding lines from: Rignot et al., 2001]

Changes on glaciers with floating ice tongues



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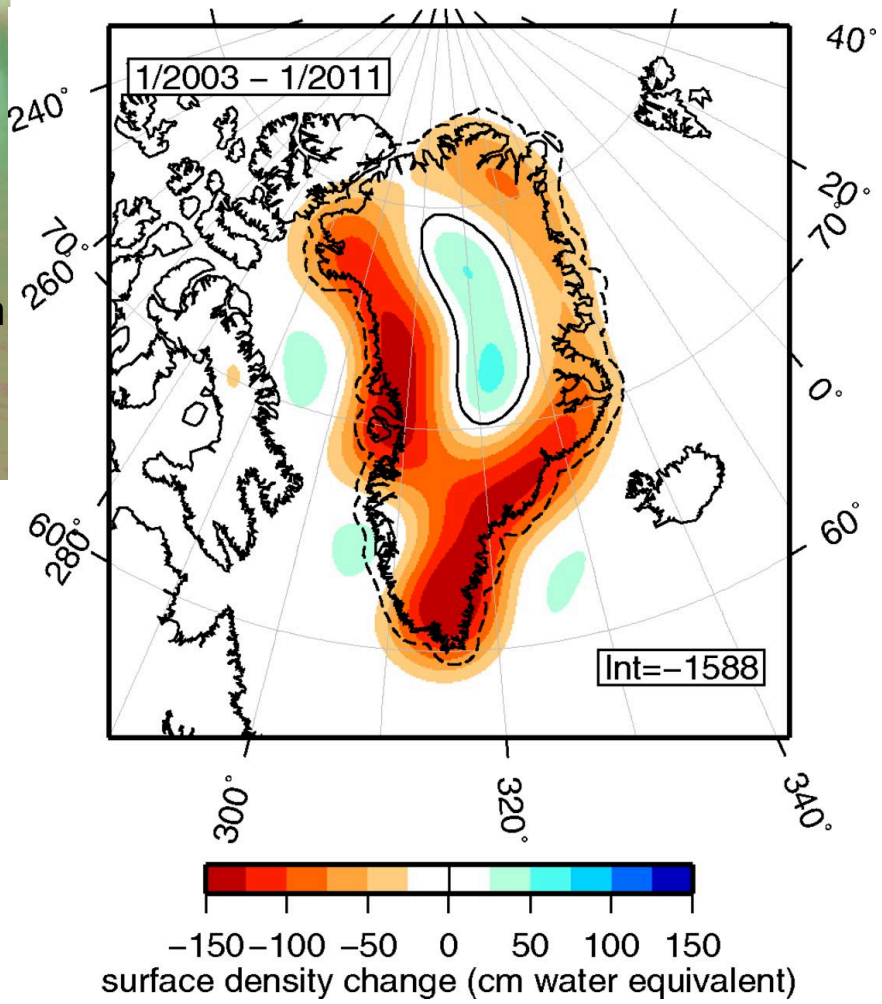
- During 2000-2010, these northern ice-shelf terminating glaciers had a negligible change in winter-to-winter velocity

- Magnitude and timing of mass loss unclear [e.g., Zwally et al., 2011; Harig & Simons, 2012]

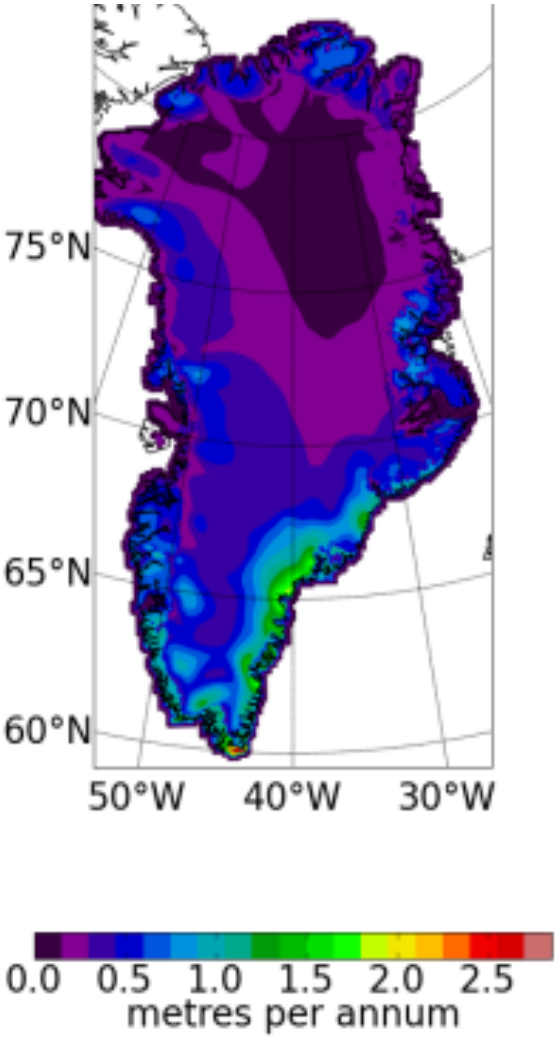
Mass loss from GRACE



[Harig & Simons, 2012]

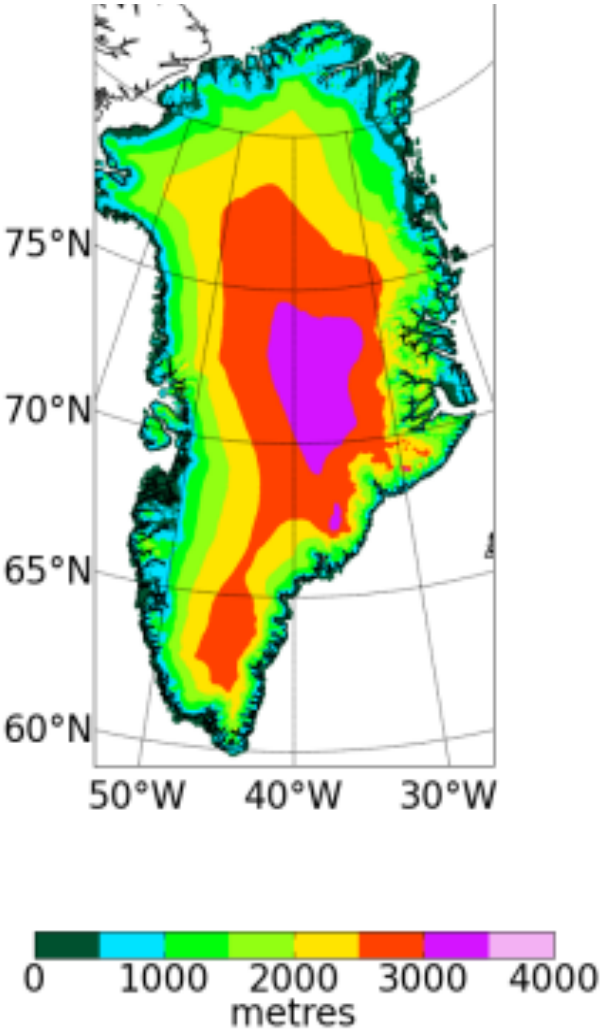
Variations in glacial setting

Precipitation



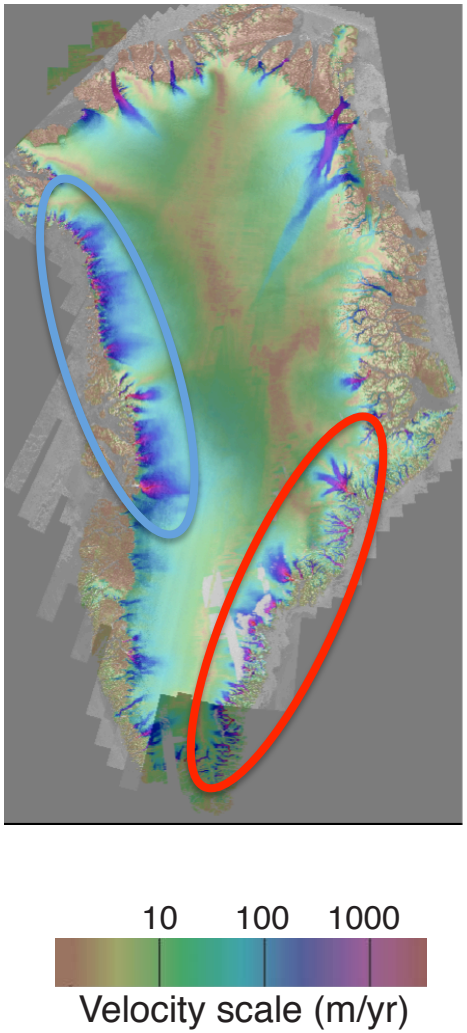
[Visualization from: CISM website]

Surface elevation

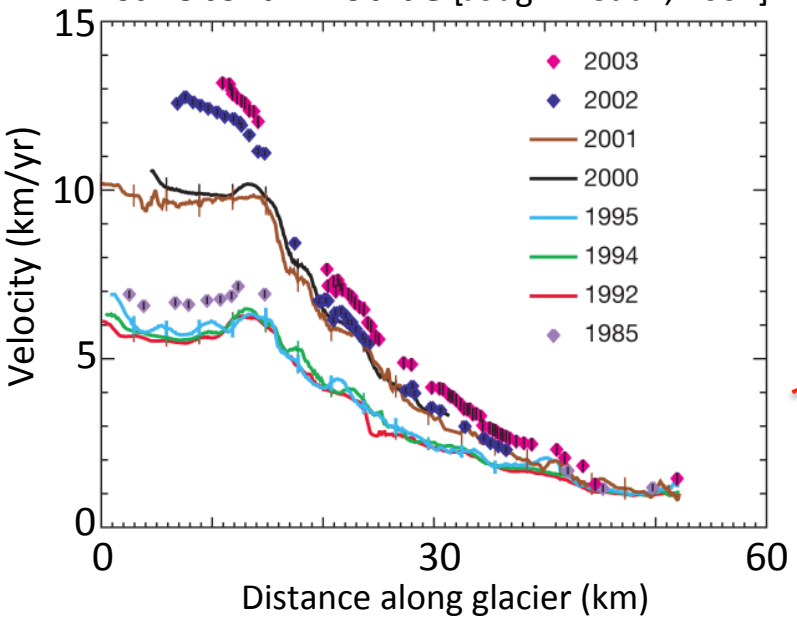


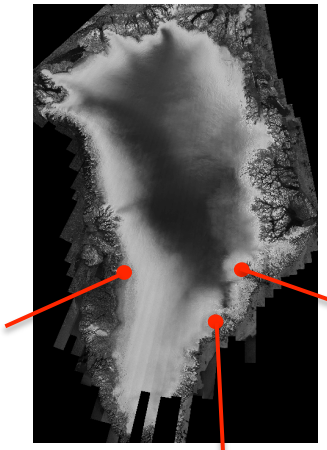
[Bamber, 2001]

Velocity

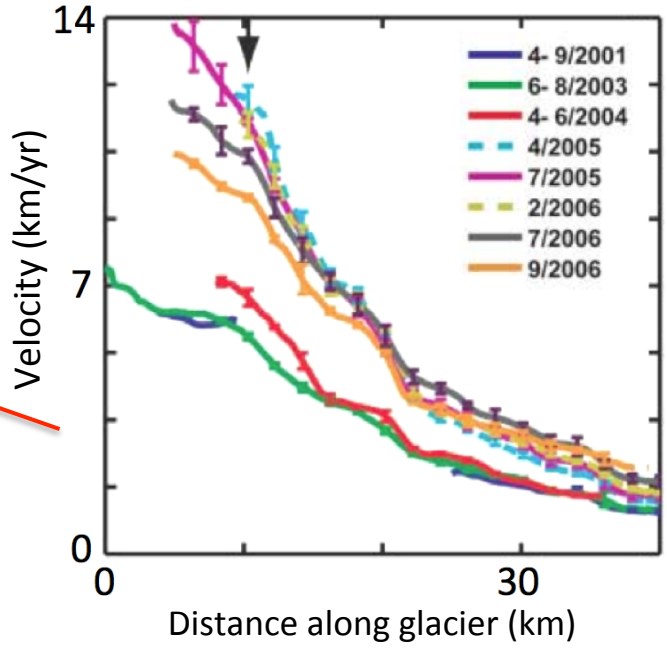


Jakobshavn Isbrae [Joughin et al., 2004]





Kangerdlugssuaq Gletscher [Howat et al., 2007]



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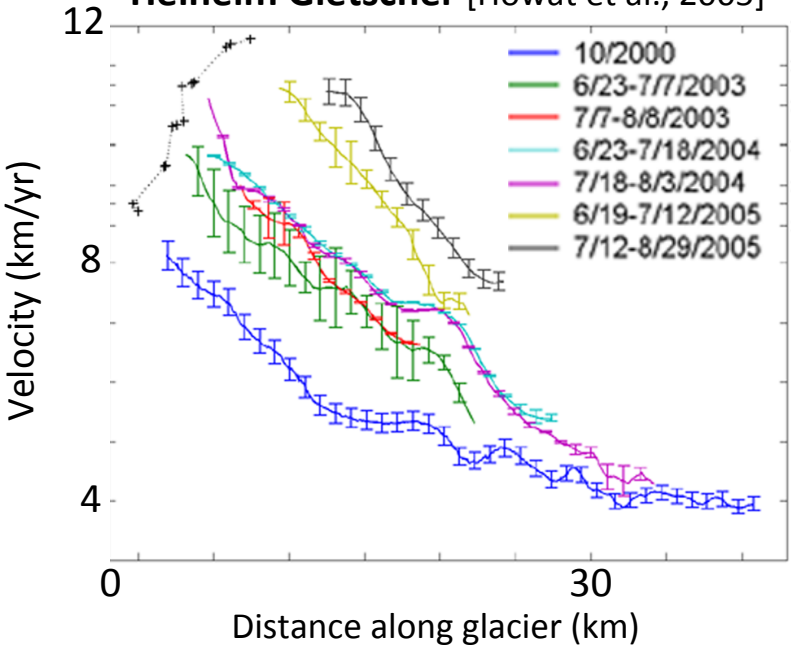

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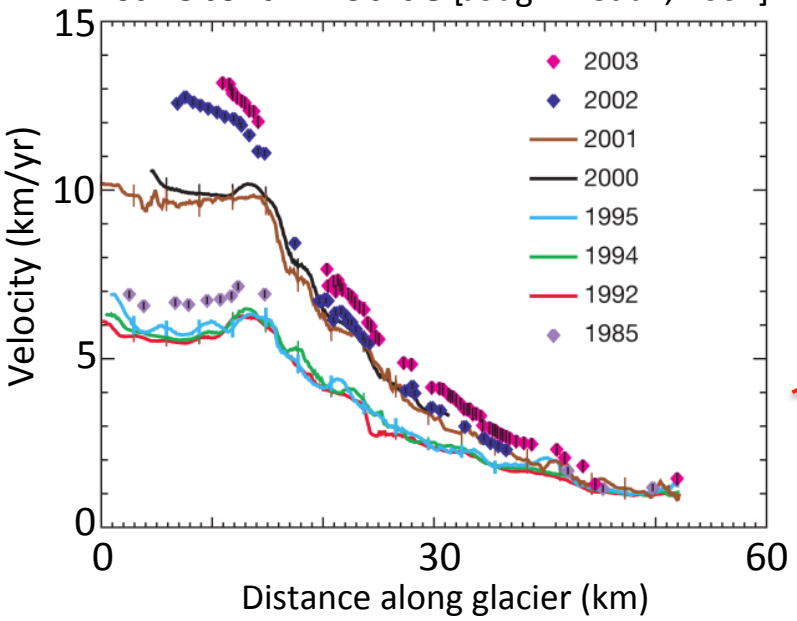

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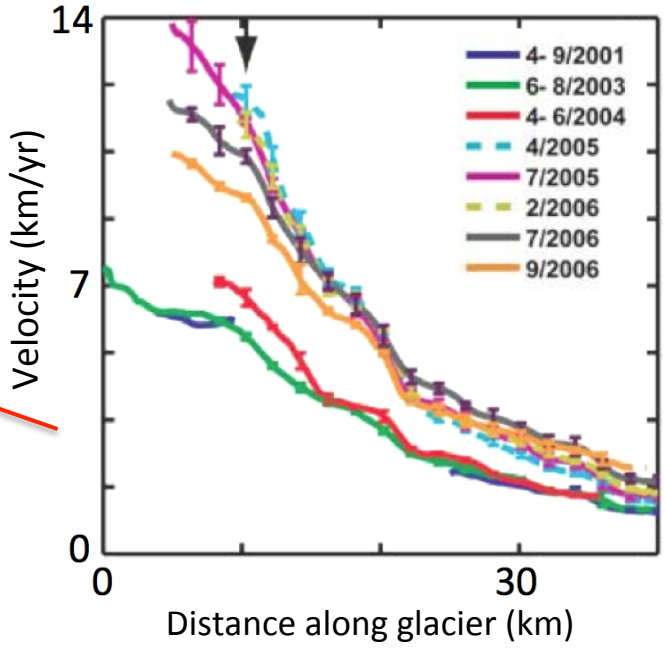

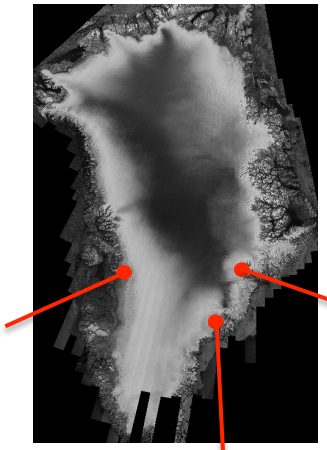

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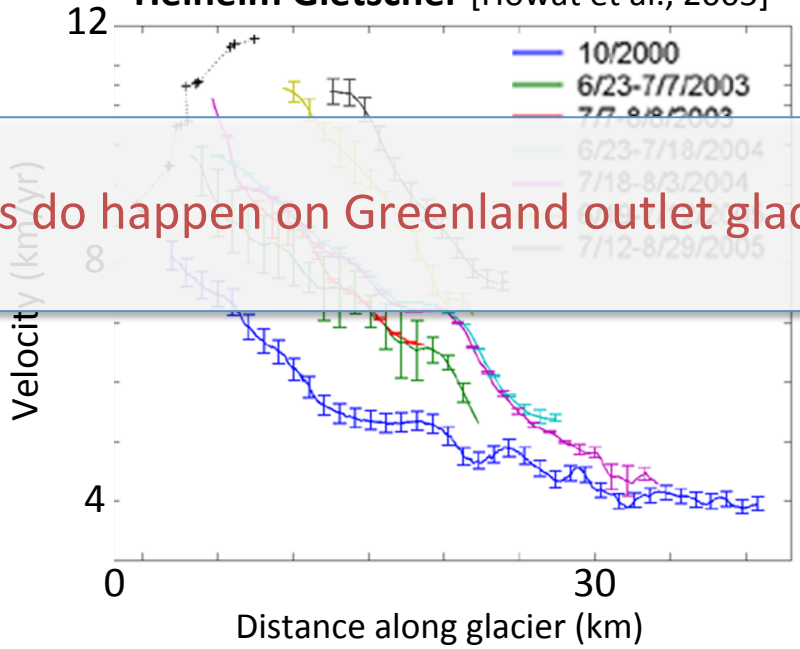
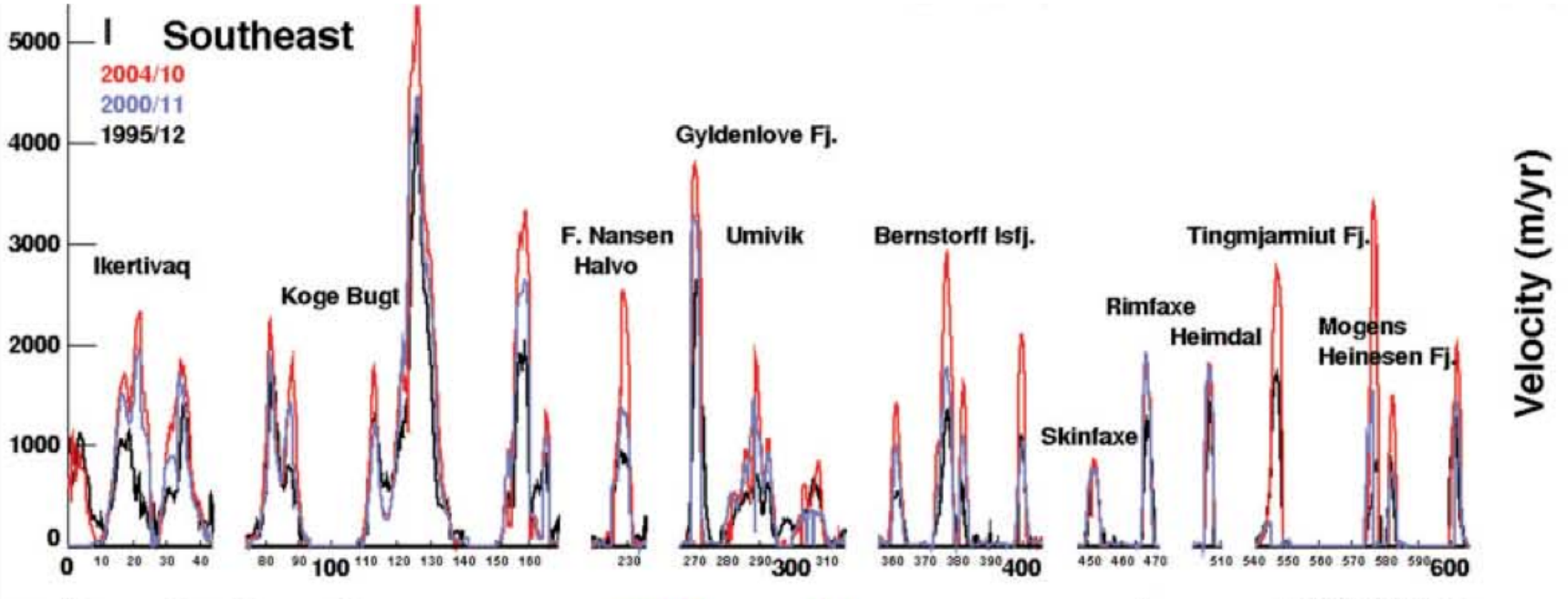


Large, rapid changes do happen on Greenland outlet glaciers.

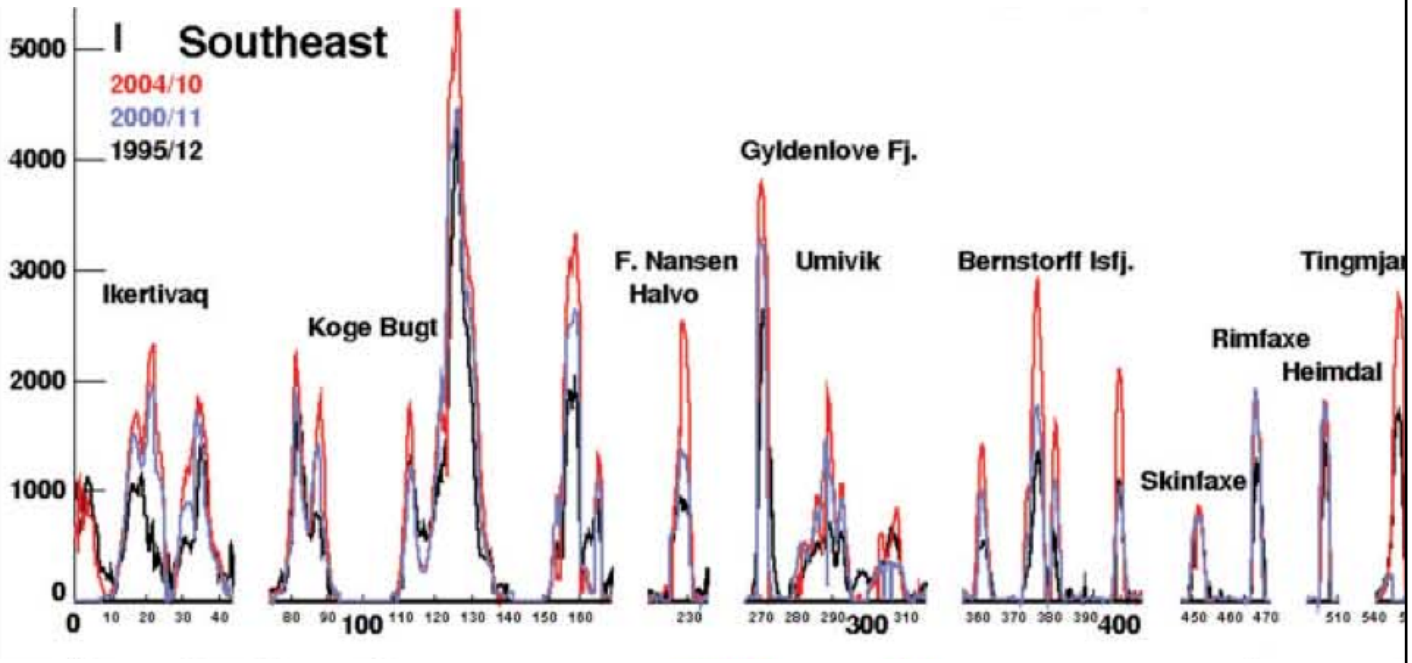
Regional signal of glacier speedup



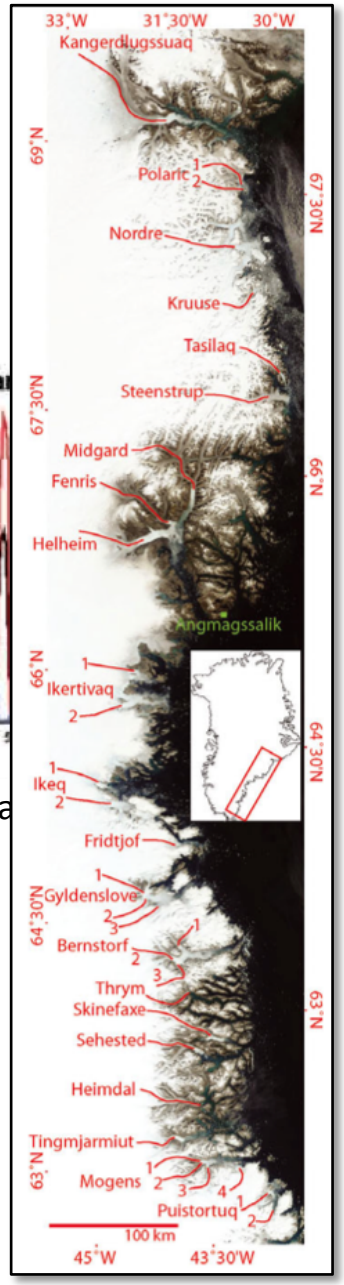
[Rignot & Kanagaratnam, 2006]

- Velocities on southeast glaciers appeared to increase consistently across the region between 1995, 2000, and 2004 measurements.

Regional signal of glacier speedup



[Rignot & Ka

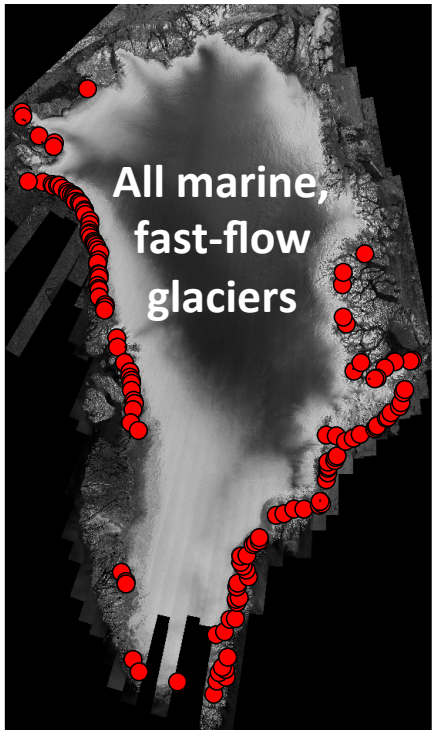


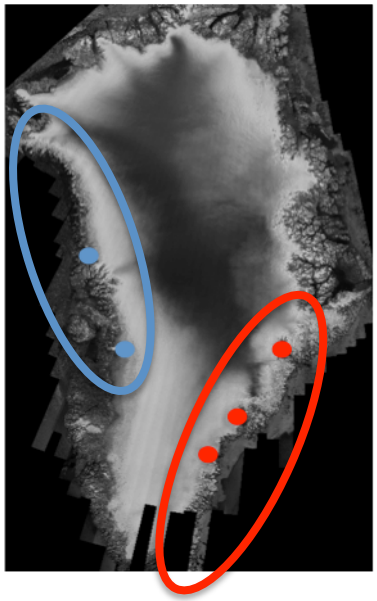
[Howat et al., 2008]

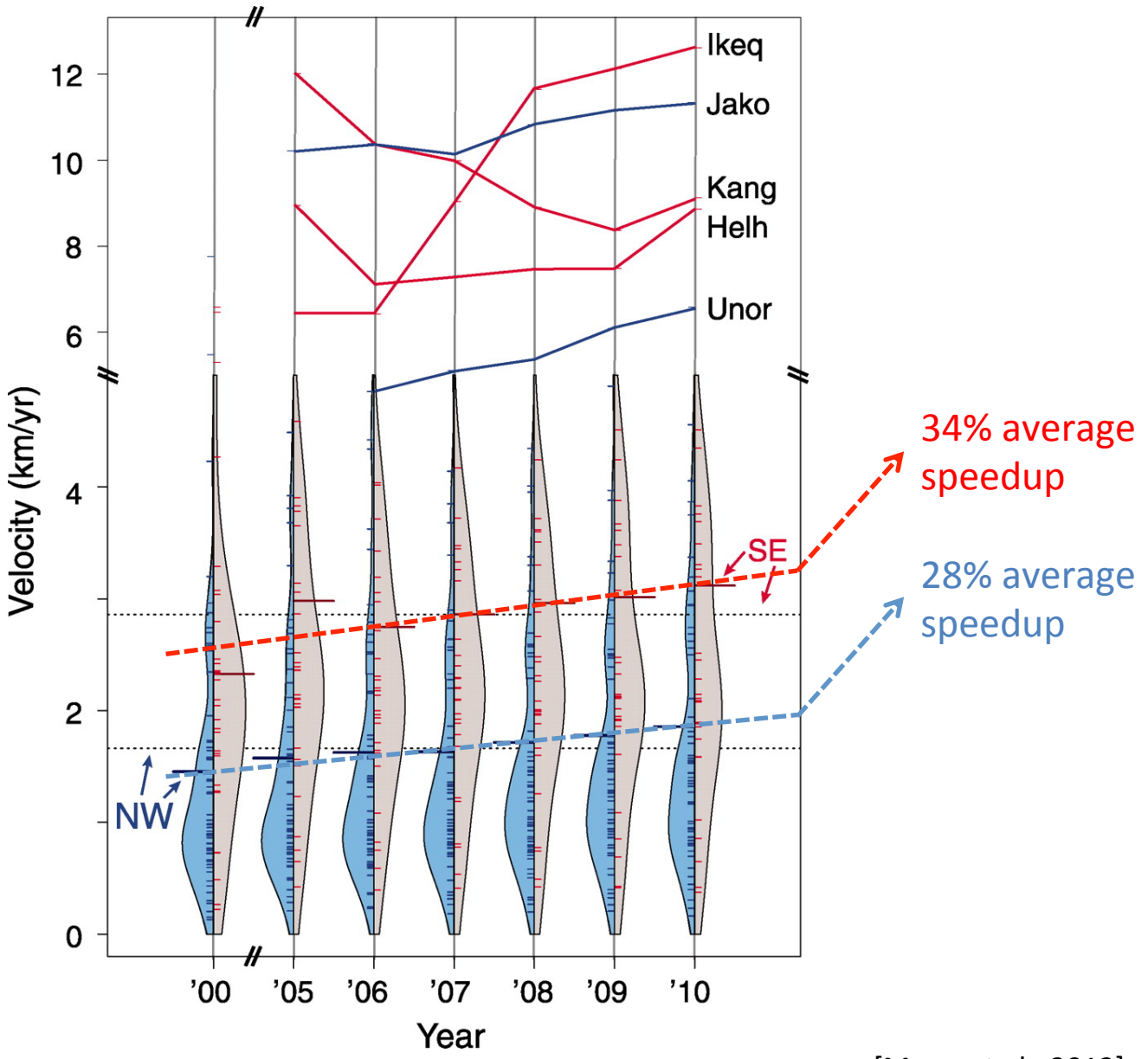
- Velocities on southeast glaciers appeared to increase consistently across the region between 1995, 2000, and 2004 measurements.

- Further observations of speedup between 2000 and 2006 suggested relatively synchronous changes, with onset potentially linked to substantially thinning in 2003

Northwest & southeast velocity patterns

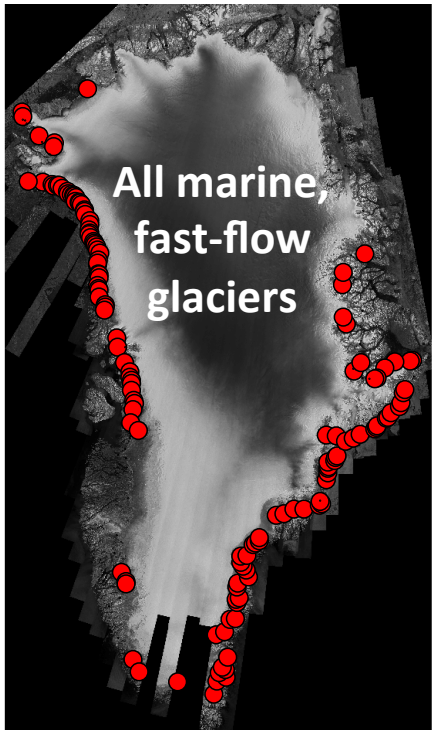


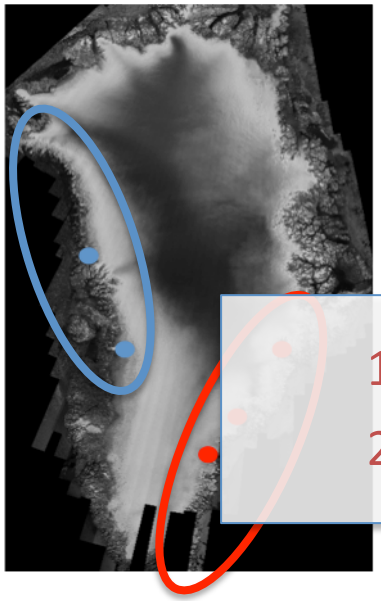


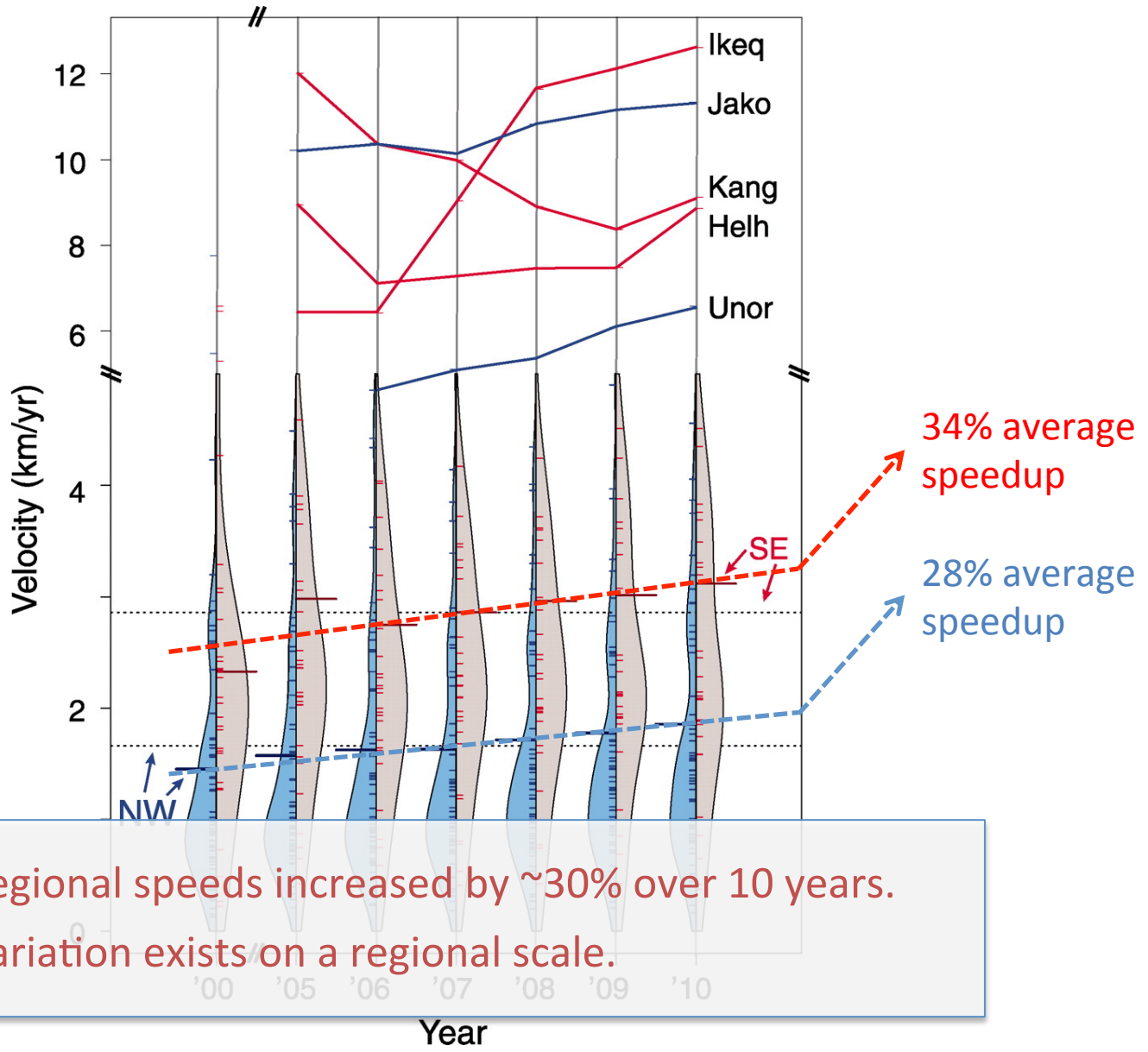


[Moon et al., 2012]

Northwest & southeast velocity patterns



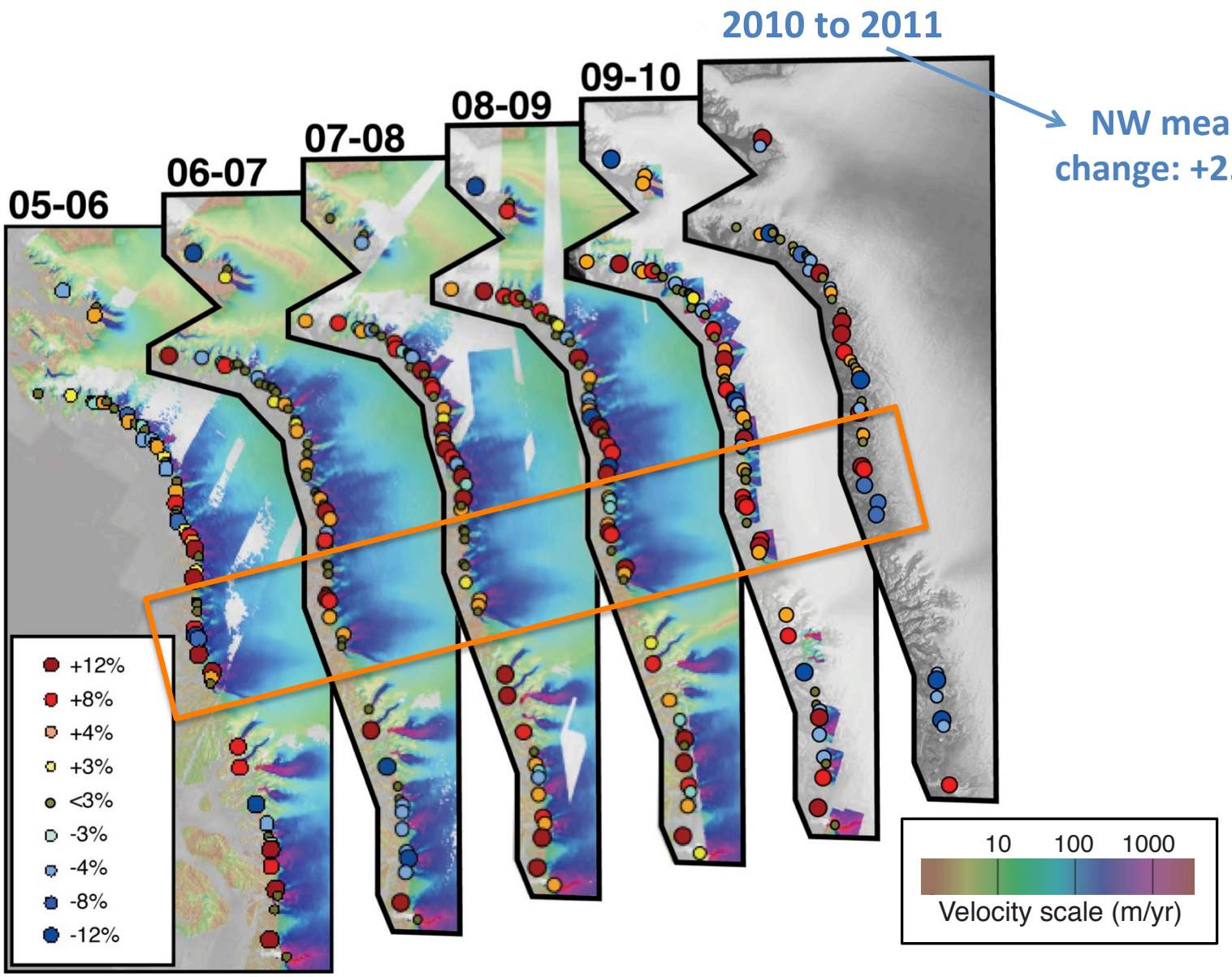




1) Regional speeds increased by ~30% over 10 years.
2) Variation exists on a regional scale.

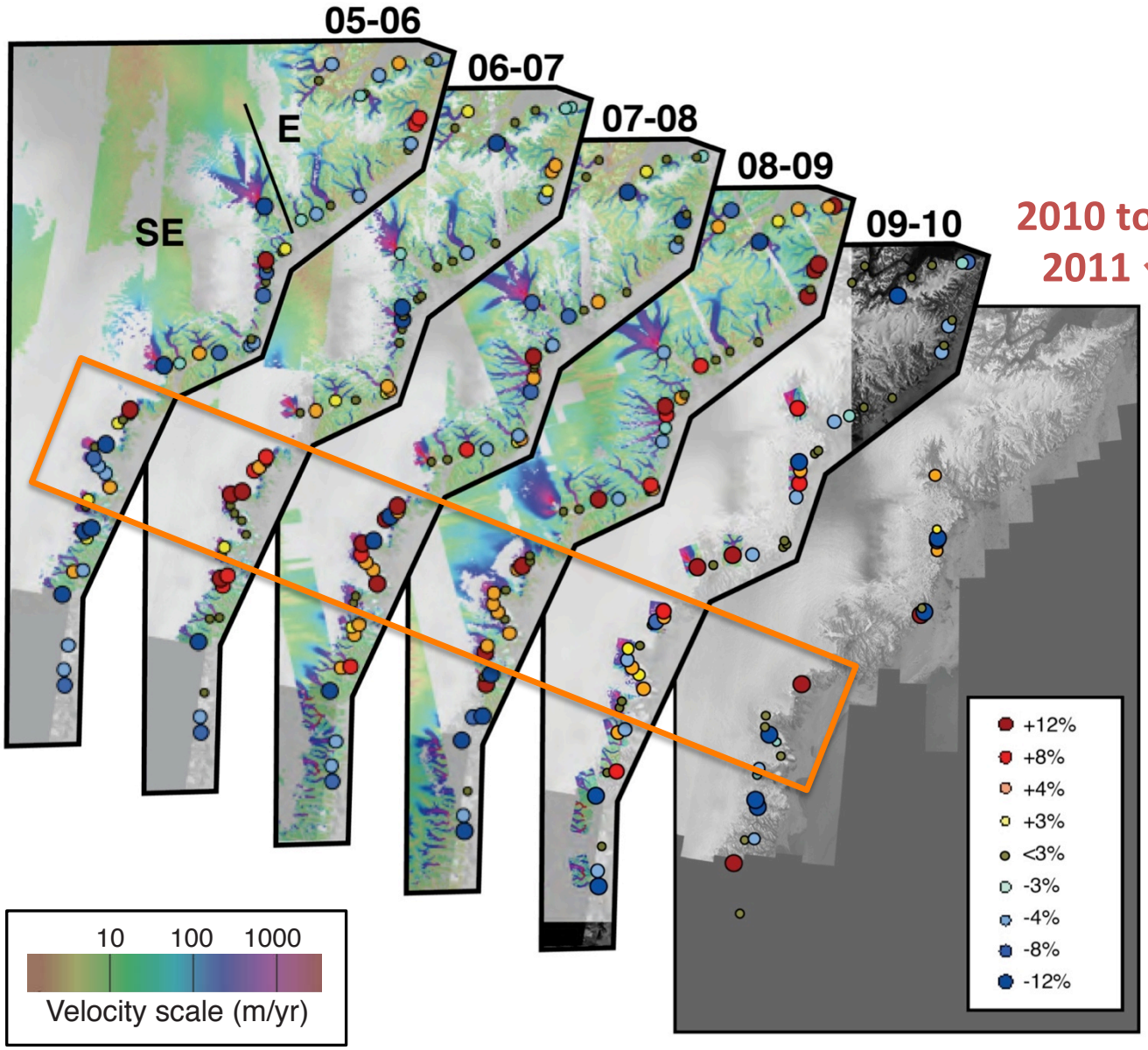
[Moon et al., 2012]

% annual velocity change



[modified from Moon et al., 2012]

% annual velocity change

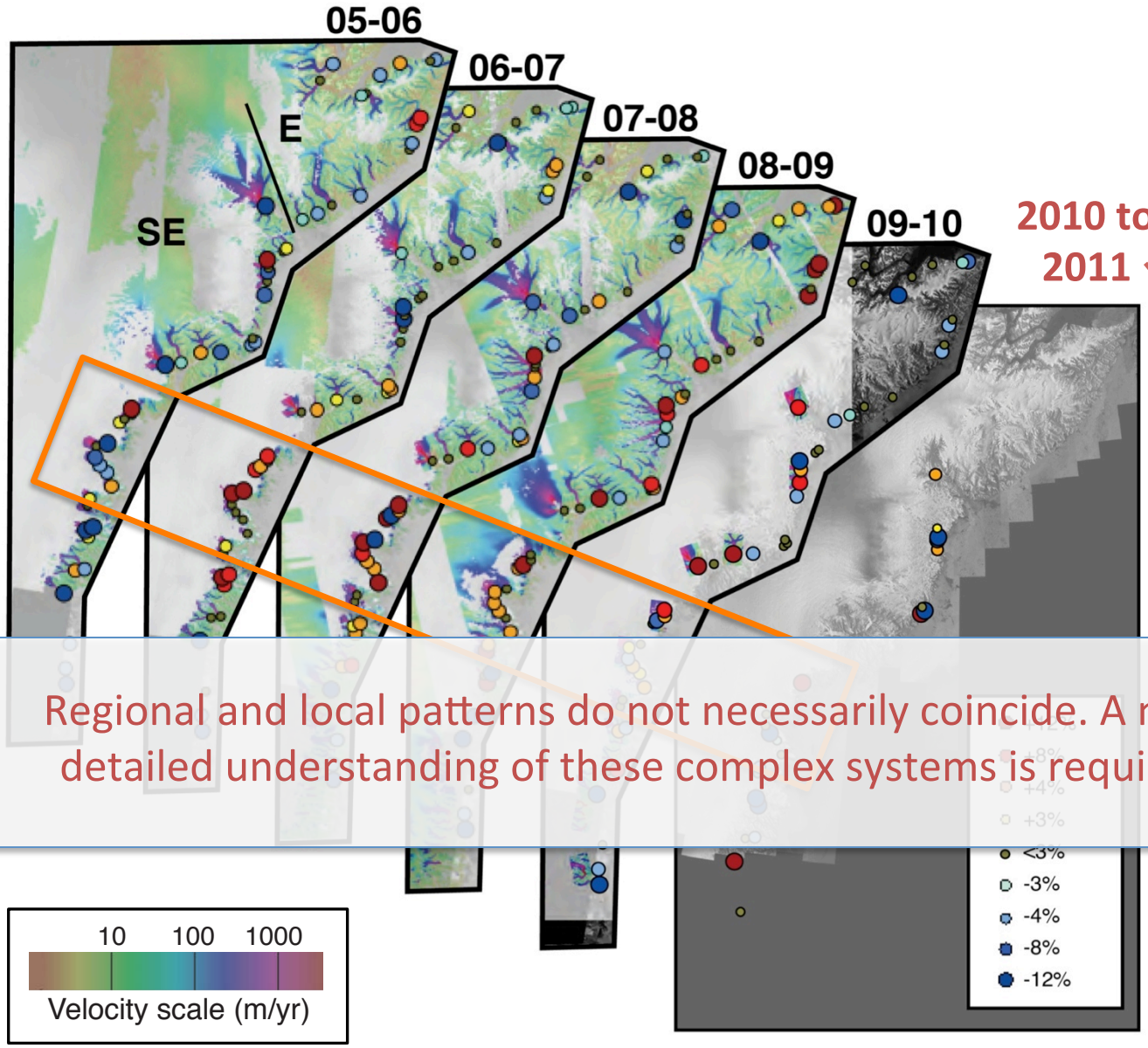


2010 to 2011

SE mean change: -0.6%

[modified from Moon et al., 2012]

% annual velocity change

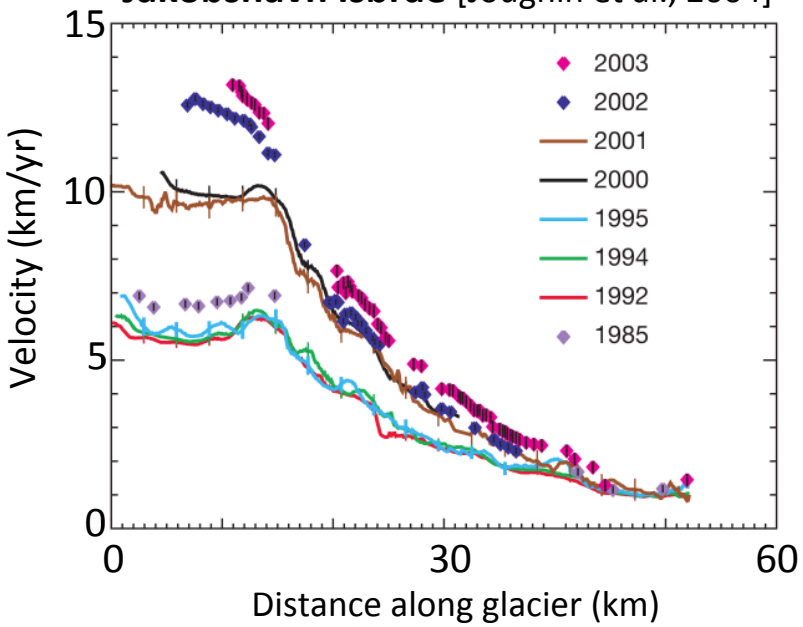


Regional and local patterns do not necessarily coincide. A more detailed understanding of these complex systems is required.

[modified from Moon et al., 2012]

Linking velocity and terminus position

Jakobshavn Isbrae [Joughin et al., 2004]



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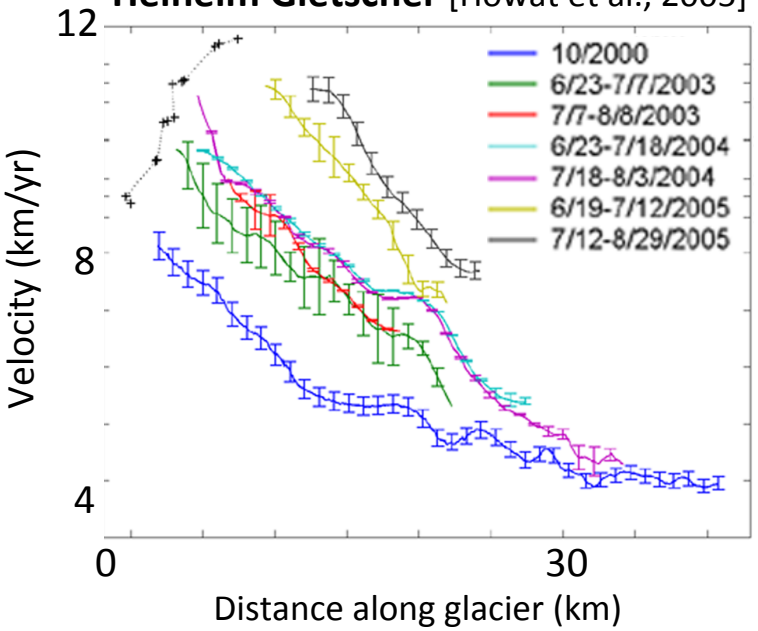
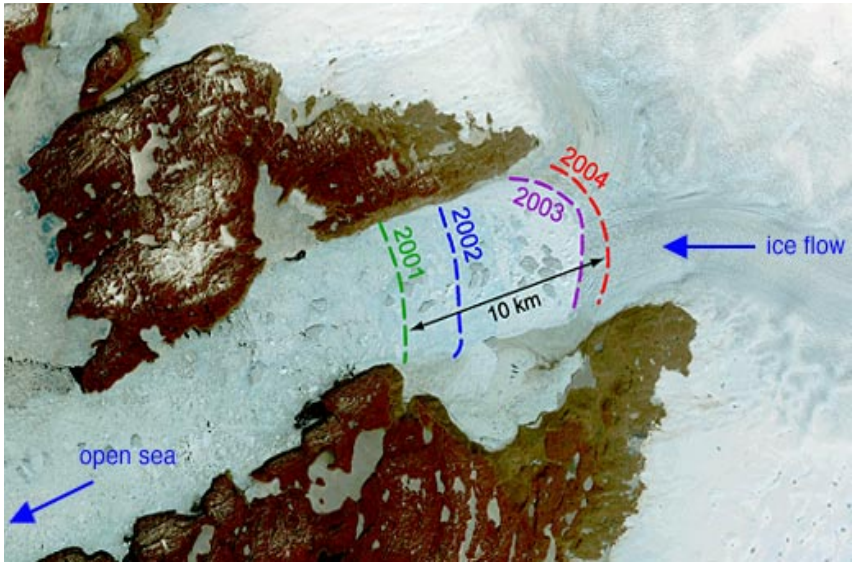
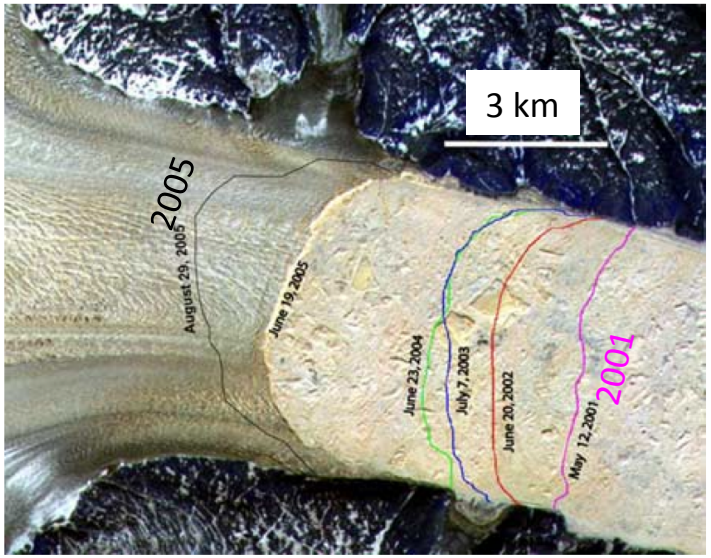


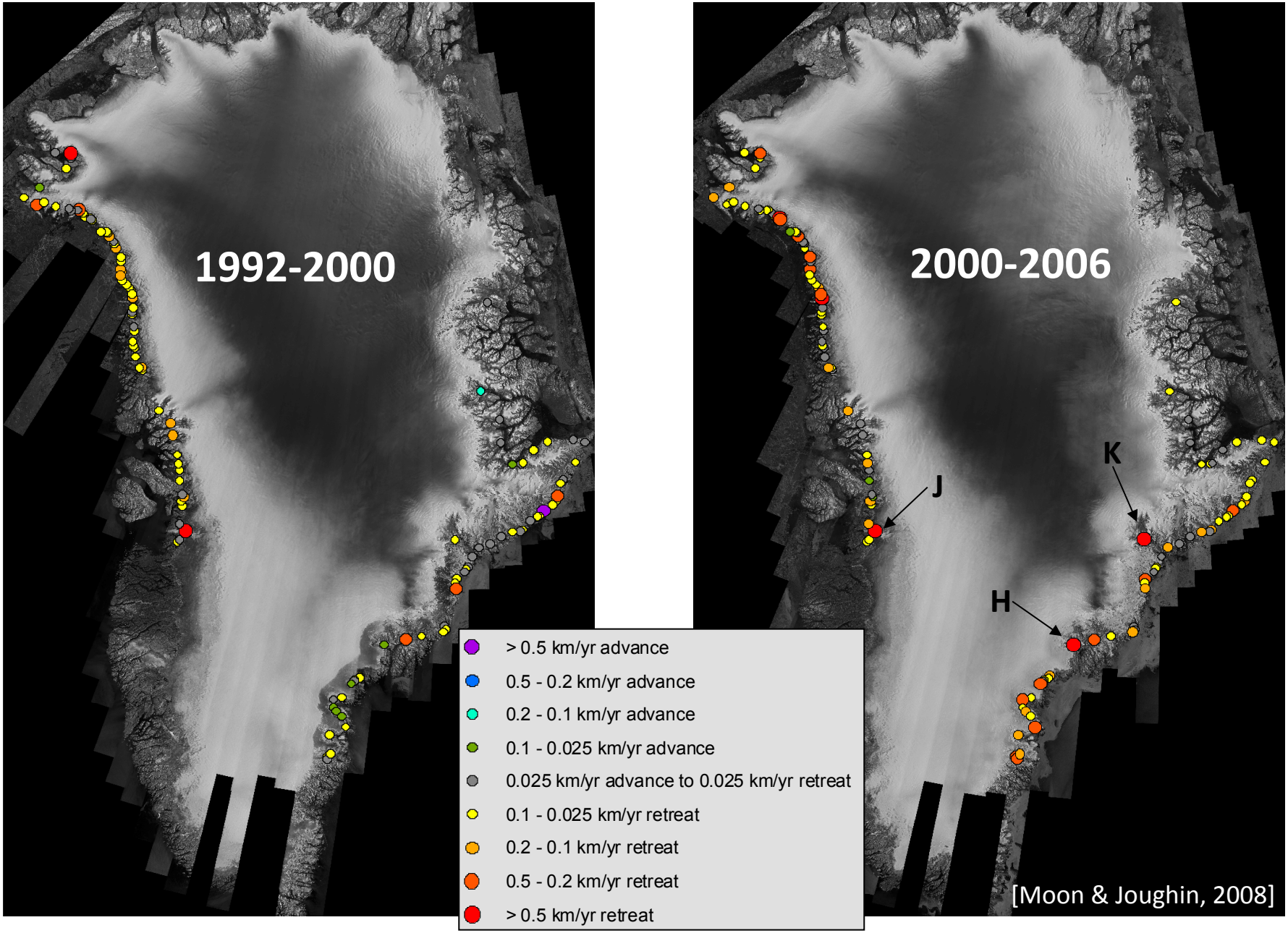


[NASA Earth Observatory]



[Howat et al., 2005]

Tidewater glacier advance and retreat



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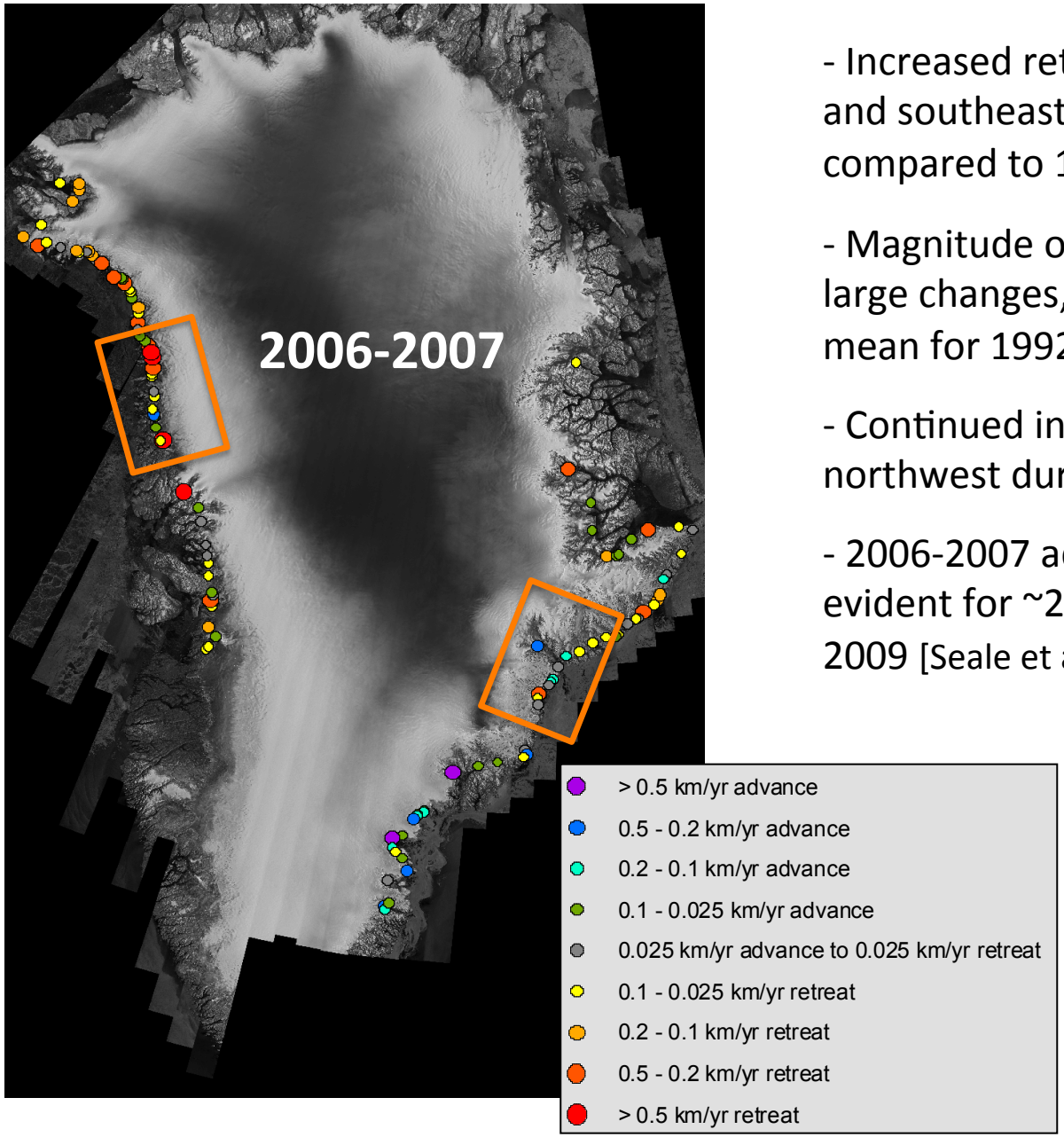


- Increased retreat in both northwest and southeast during 2000-2006 as compared to 1992-2000

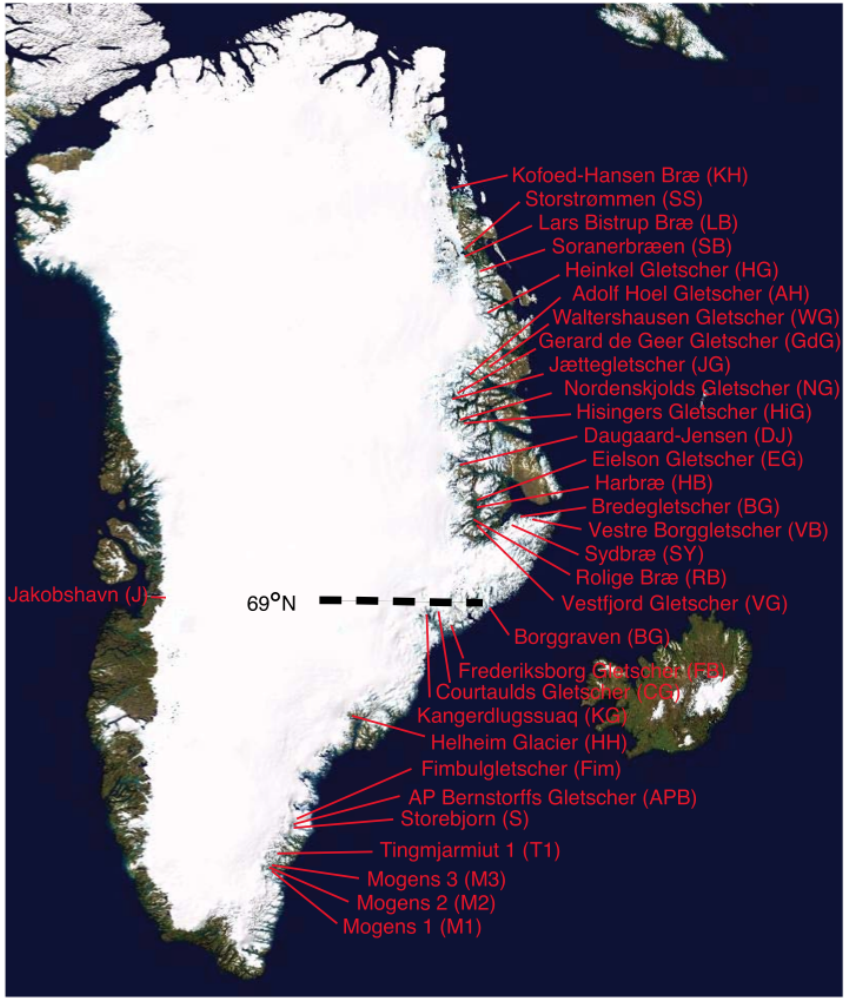
- Magnitude of change driven by few large changes, but median follows mean for 1992-2006

- Continued increase retreat in northwest during 2006-2007

- 2006-2007 advance in southeast, evident for ~25% of glaciers through 2009 [Seale et al., 2011]

[Moon & Joughin, 2008]

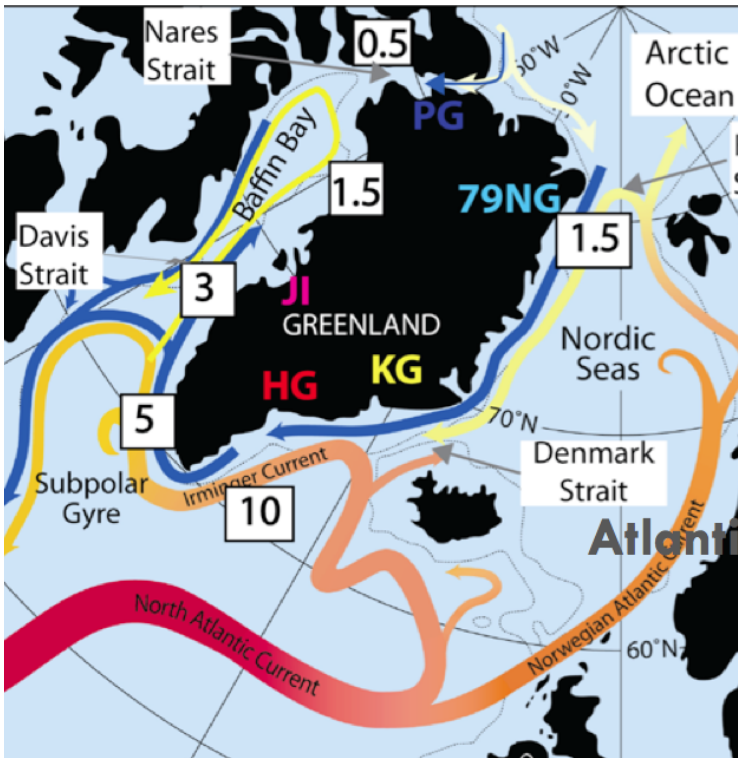
East Greenland terminus change 2000-2009 – Seale et al., 2011



[Seale et al., 2011]

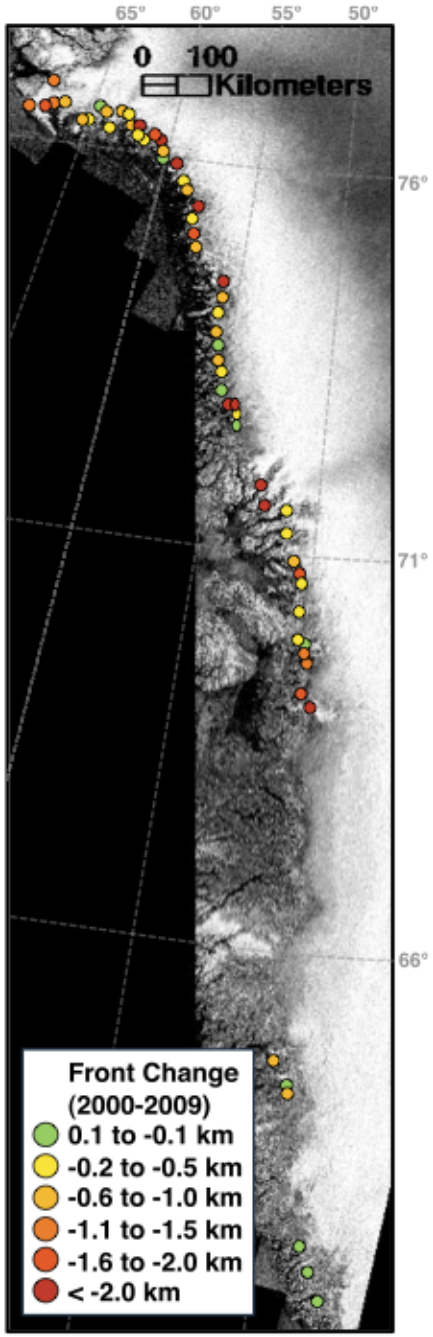
- Distinct difference in interannual terminus change north and south of 69°N

- Suggest difference is due to exposure to warm ocean currents



[Straneo et al., 2010]

West Greenland terminus change 2000-2009
– McFadden et al., 2011; Howat et al., 2010



[McFadden et al., 2011]

- Widespread retreat and thinning

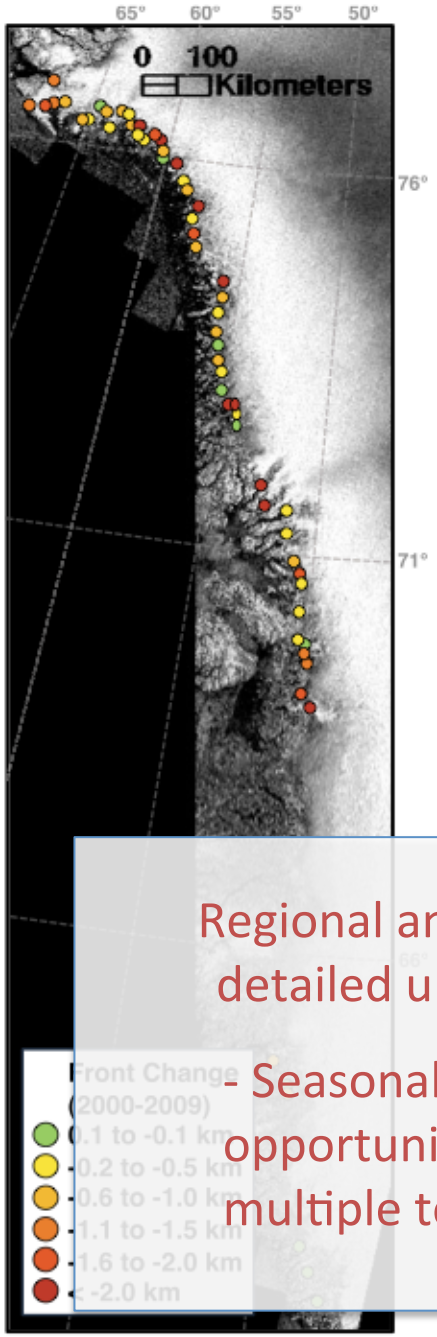
- Examined terminus position, surface elevation and slope, and velocity, and climate data – no consistent connection among velocity, front position, and external forcing

[Howat et al., 2010]

- With exception of Rink Isbrae, velocity not correlated with seasonal terminus position – perhaps more closely linked to hydrologic system

- Looking at seasonal-scale changes, seasonal terminus changes correlate with ice mélange patterns

West Greenland terminus change 2000-2009
– McFadden et al., 2011; Howat et al., 2010



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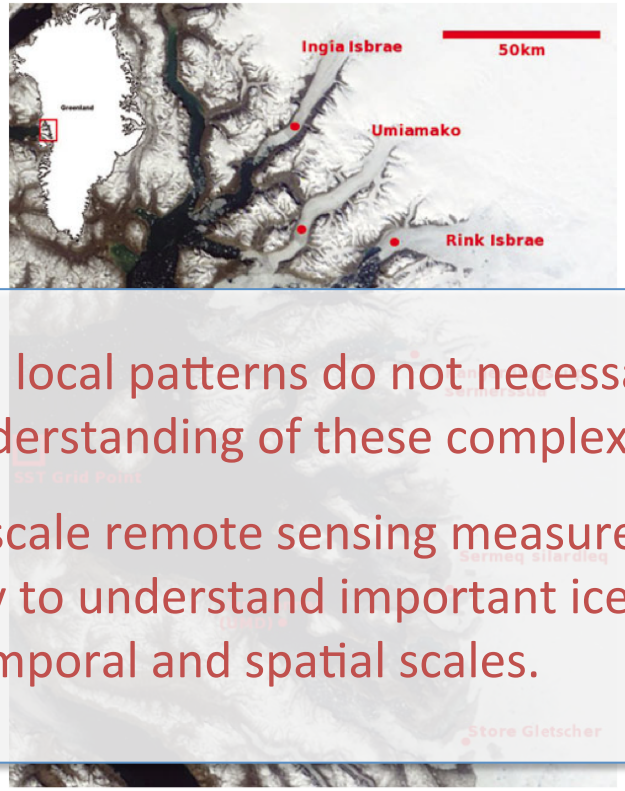

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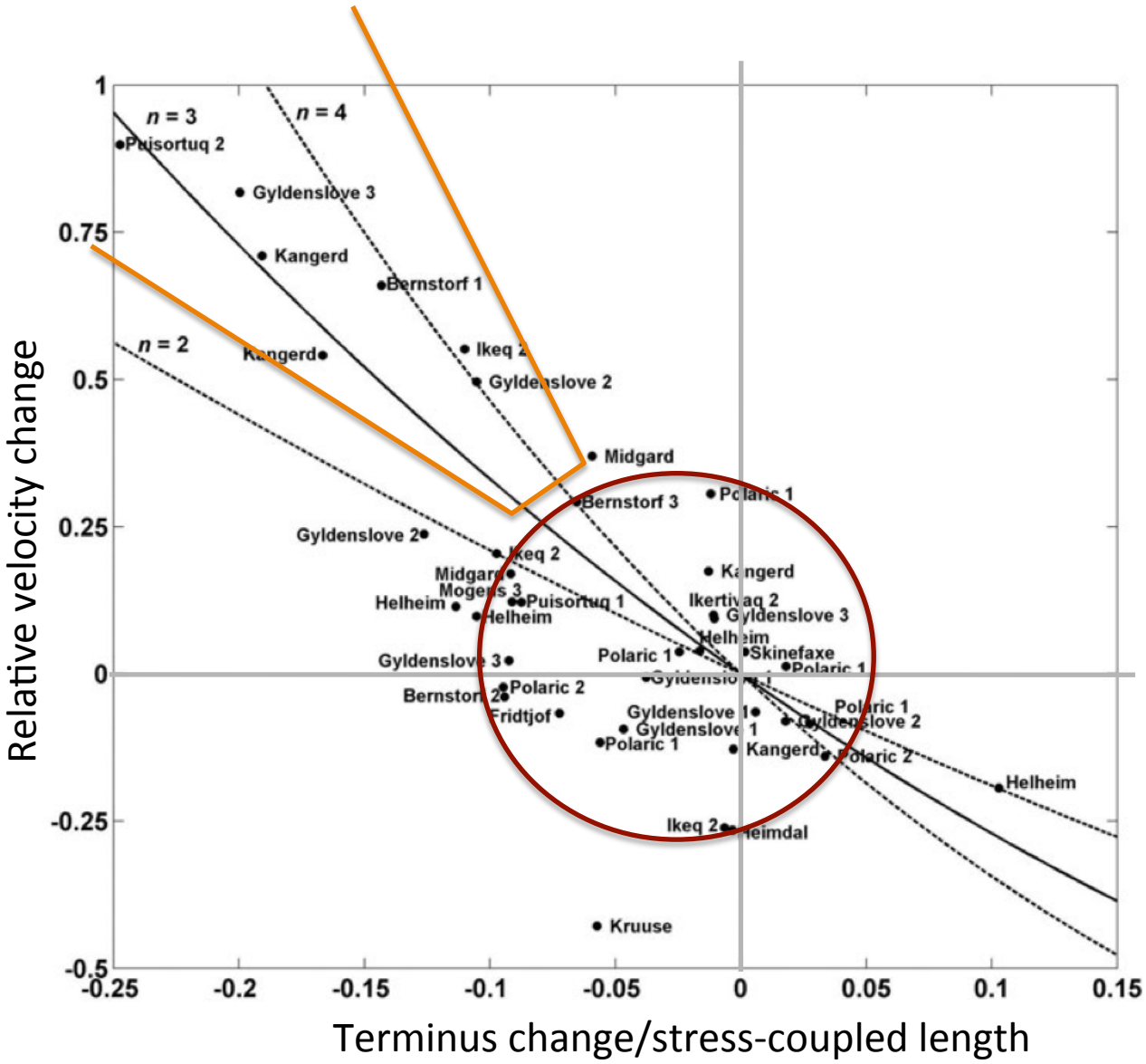
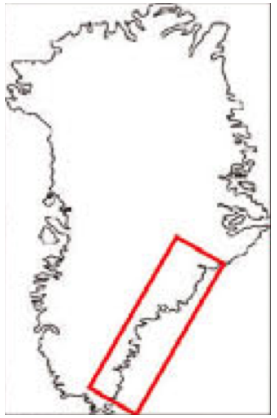
Regional and local patterns do not necessarily coincide. A more detailed understanding of these complex systems is required.

- Seasonal-scale remote sensing measurements may be a key opportunity to understand important ice-ocean mechanisms on multiple temporal and spatial scales.

Linking velocity and terminus position



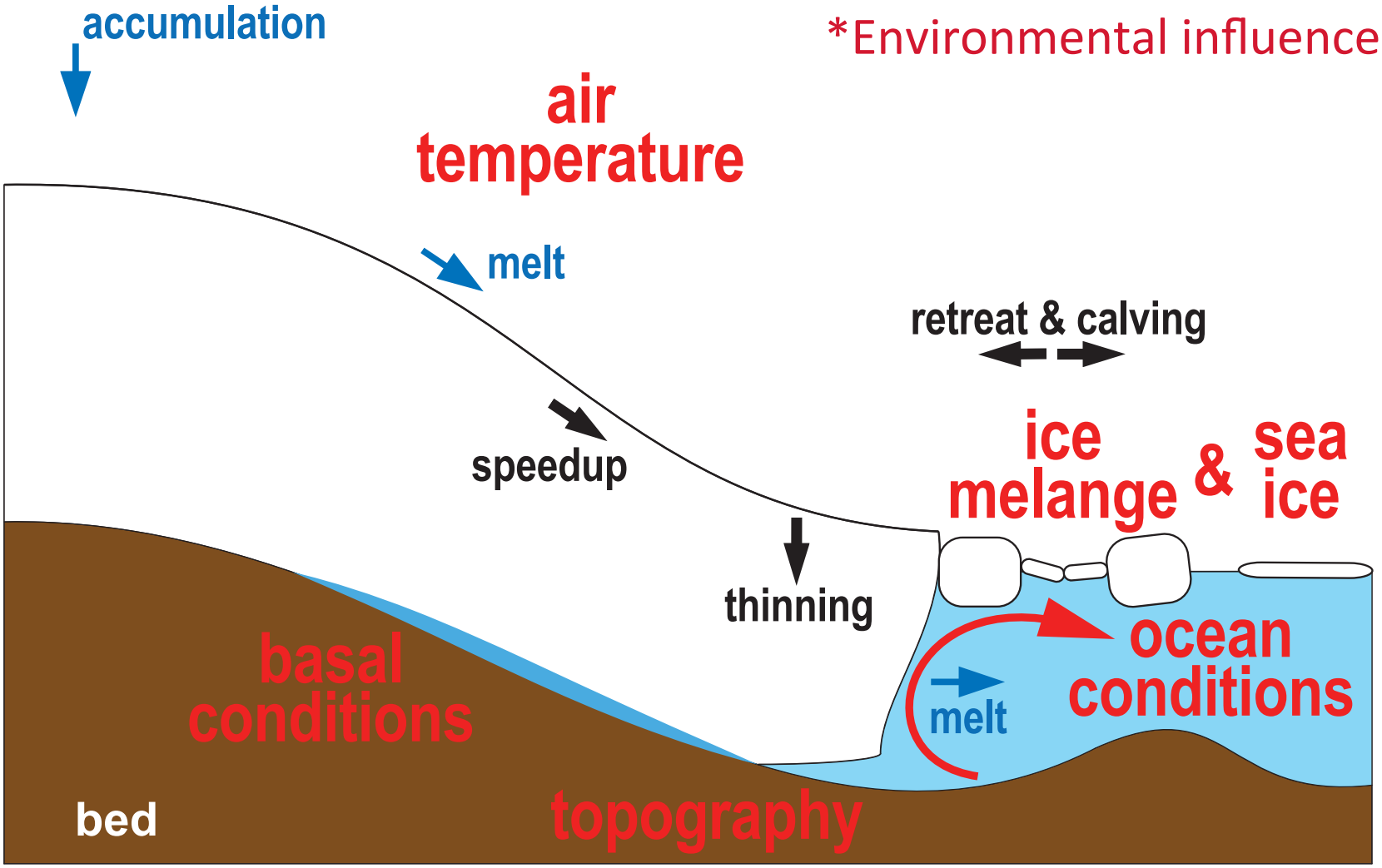


[Howat et al., 2008]

*SMB components

*Ice discharge components

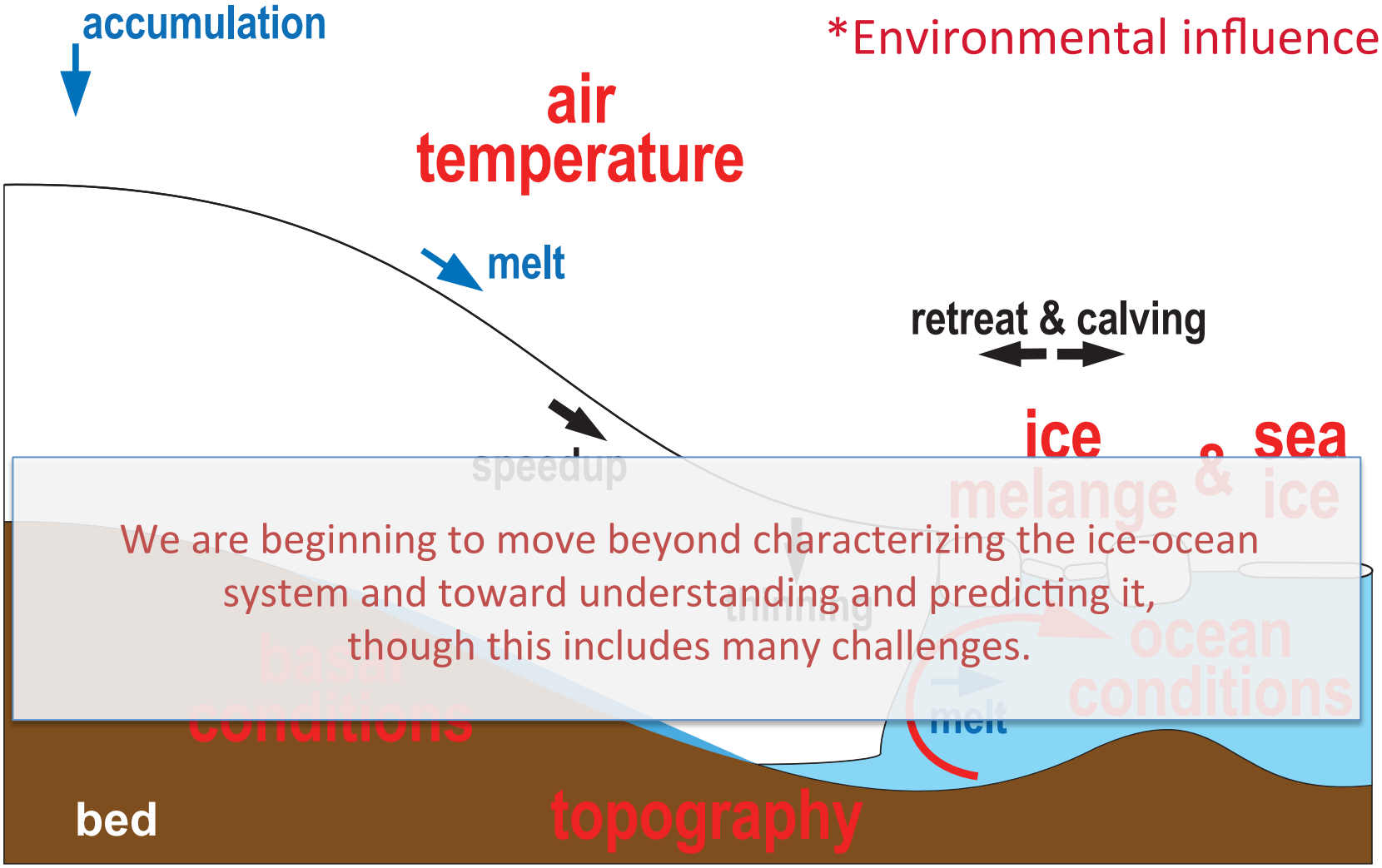
*Environmental influences



*SMB components

*Ice discharge components

*Environmental influences



We are beginning to move beyond characterizing the ice-ocean system and toward understanding and predicting it, though this includes many challenges.

- **Over a broad scale:**
  - Notable area loss of floating ice tongues on northern ice-shelf—terminating glaciers since 2000, but little velocity or mass loss signal
  - Tidewater glaciers have overall patterns of retreat and speedup, with a clear mass loss signal in the northwest and southeast

- **Using a more focused spatial/temporal lens:**
  - Velocity and terminus position appear dependent on environmental factors of individual glaciers
  - Forcing signals from specific environmental factors still difficult to distinguish through observations of ice dynamics

- **Needed:**
  - Continued – and improved – spatial and temporal remote sensing data to help overcome the limits of our “short” observation period
  - Joint efforts in modeling and observation to parse out the spatial and temporal scales and magnitudes of change associated with different climatic and environmental elements