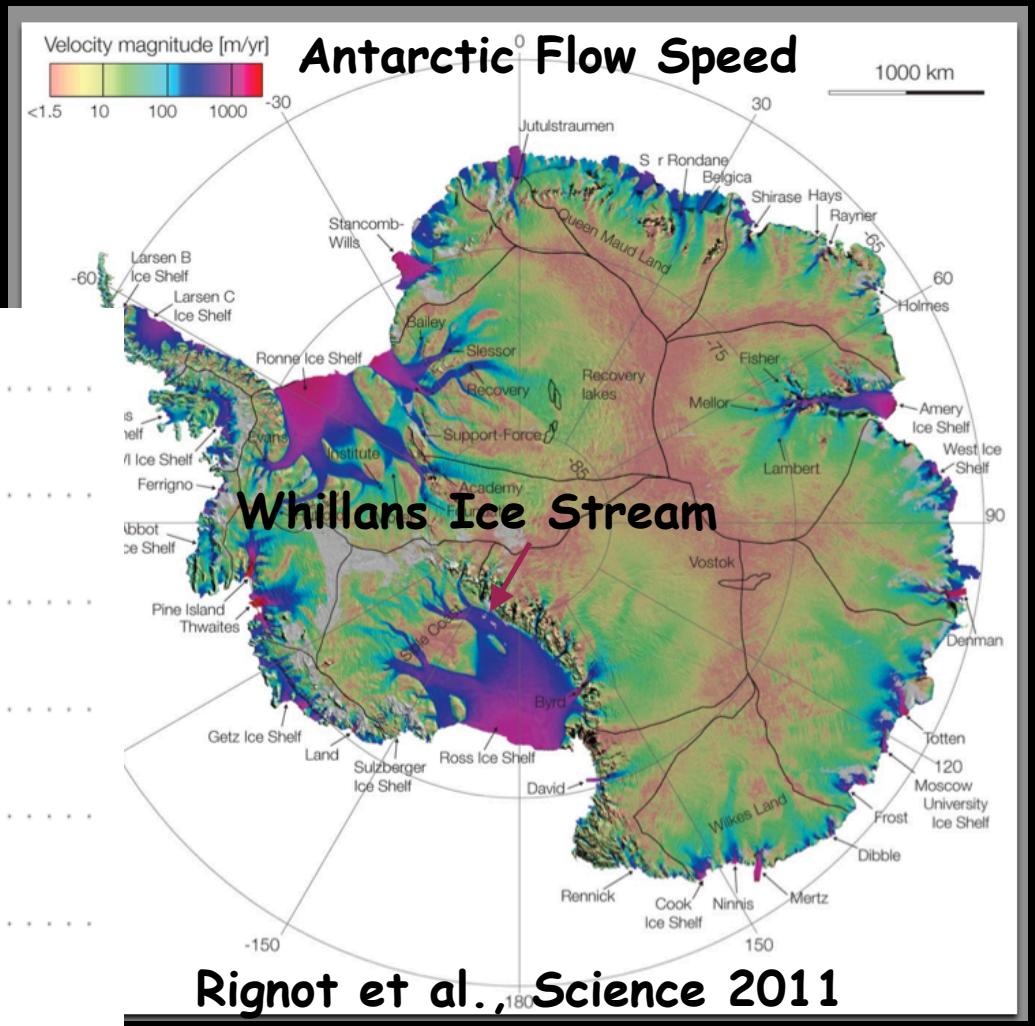
Skipped Slips, Stick-slip and the Slow Down of Whillans Ice Stream, Antarctica

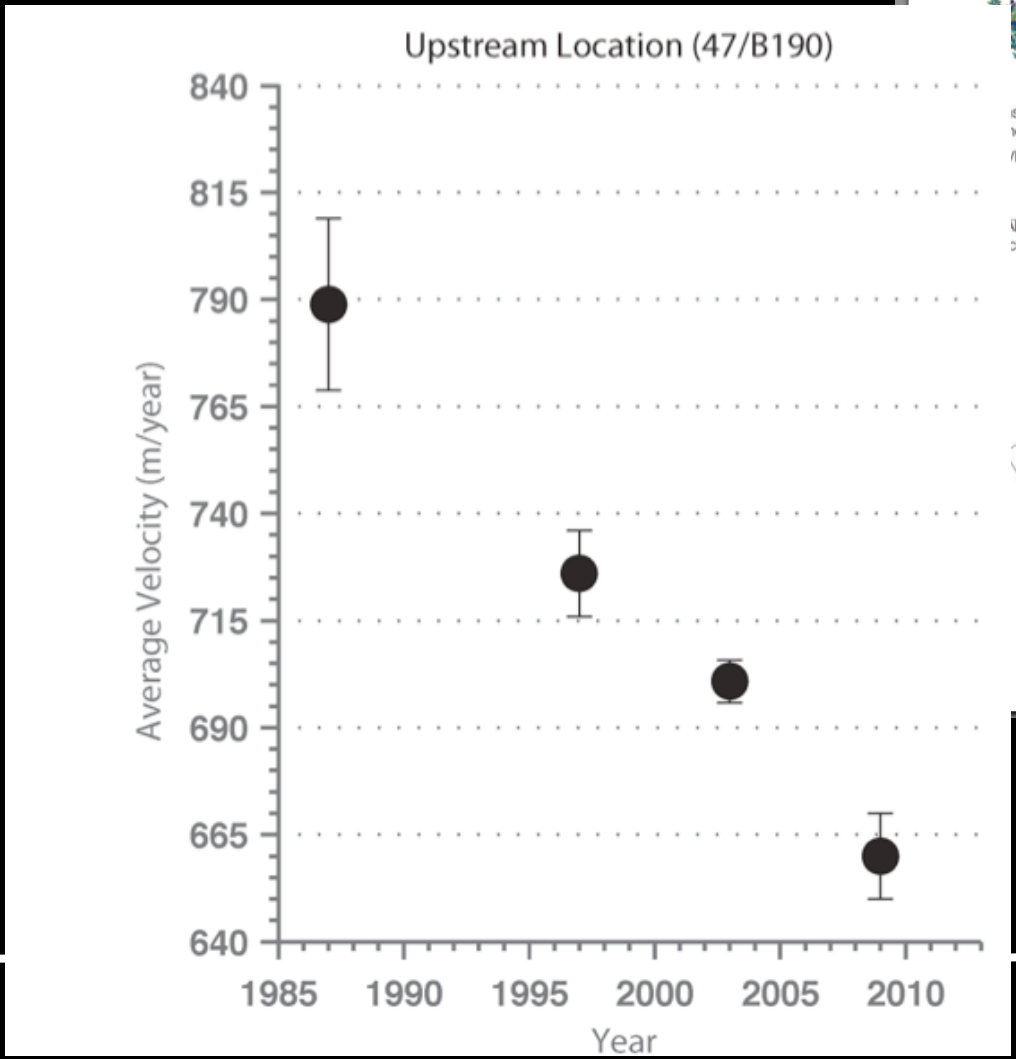
Paul Winberry (Central Washington)
Sridhar Anandakrishnan and Richard Alley (Penn State)
Doug Wiens (Washington Univ. in Saint Louis),

Whillans Ice Stream is a major route for ice leaving WAIS

Interesting for several Reasons

1) Slowing-Down
2) Active Lakes
3) Moves By Stick-Slip





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Don Voigt, Leo Peters (Penn State), Matt King (Newcastle), Robert Bindschadler (NASA), Huw Horgan (Victoria Univ.-N.Z.), Ginny Catania (Univ. of Texas), Sarah Das (Woods Hole), Audrey Huerta (Central Washington), Ian Joughin (UDub), Alex Brisbourne, Martin Pratt,Peter Burkett,Randy Justin, Steph Kay, Angie Hoffer.....

NSIDC + many others for data....

Laurie Padman's Tide Model

Raytheon Polar Services, New York Air National Guard, Ken Borek Air, UNAVCO, PASSCAL

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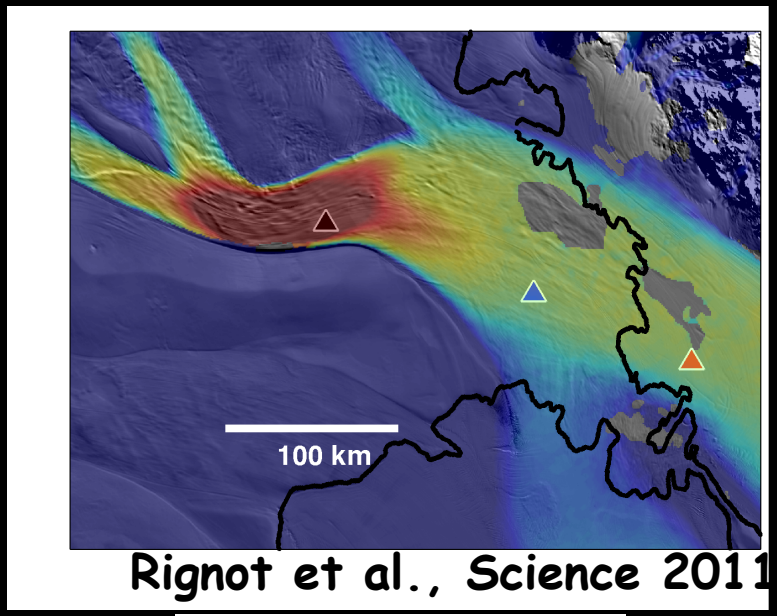
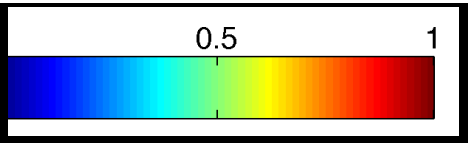
Whillans Ice Stream is Sticking and Slipping

Average Velocity



Rignot et al., Science 2011

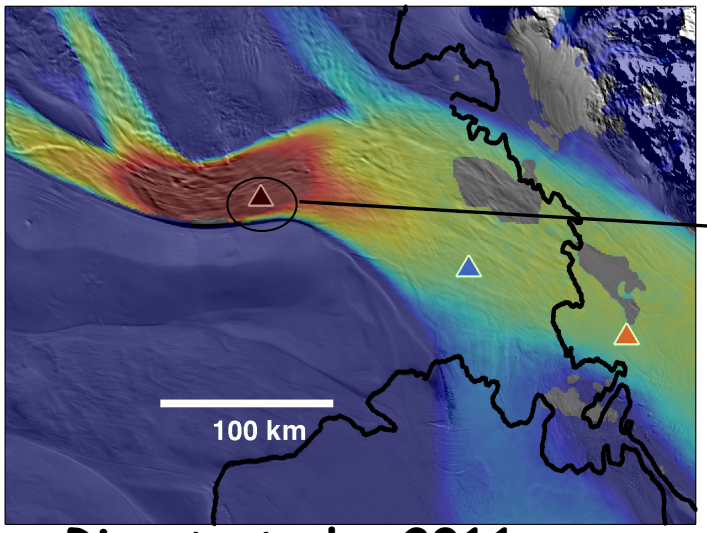


(m/day)

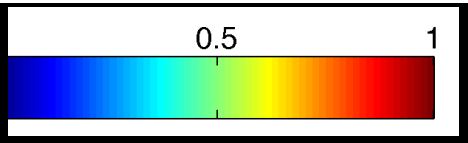
Whillans Ice Stream is Sticking and Slipping

Average Velocity

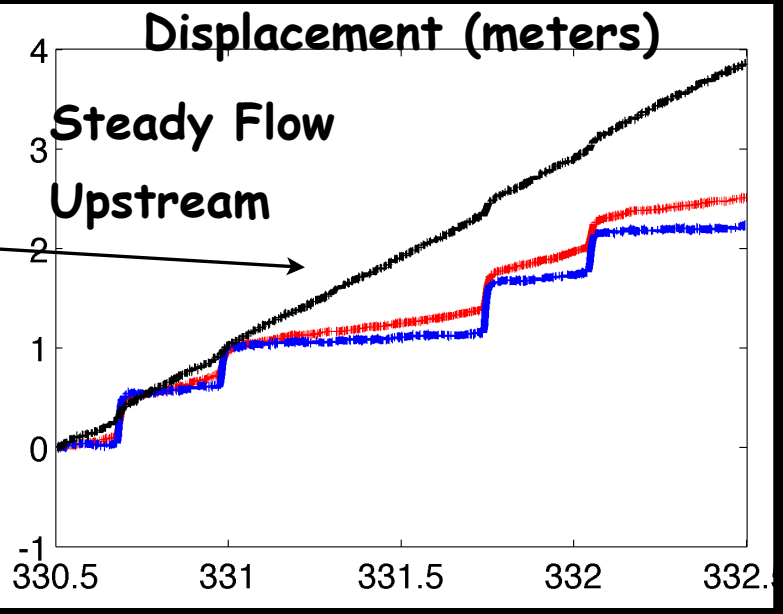
GPS time-series
for 2 Days



Rignot et al., 2011



(m/day)



Day of Year 2003

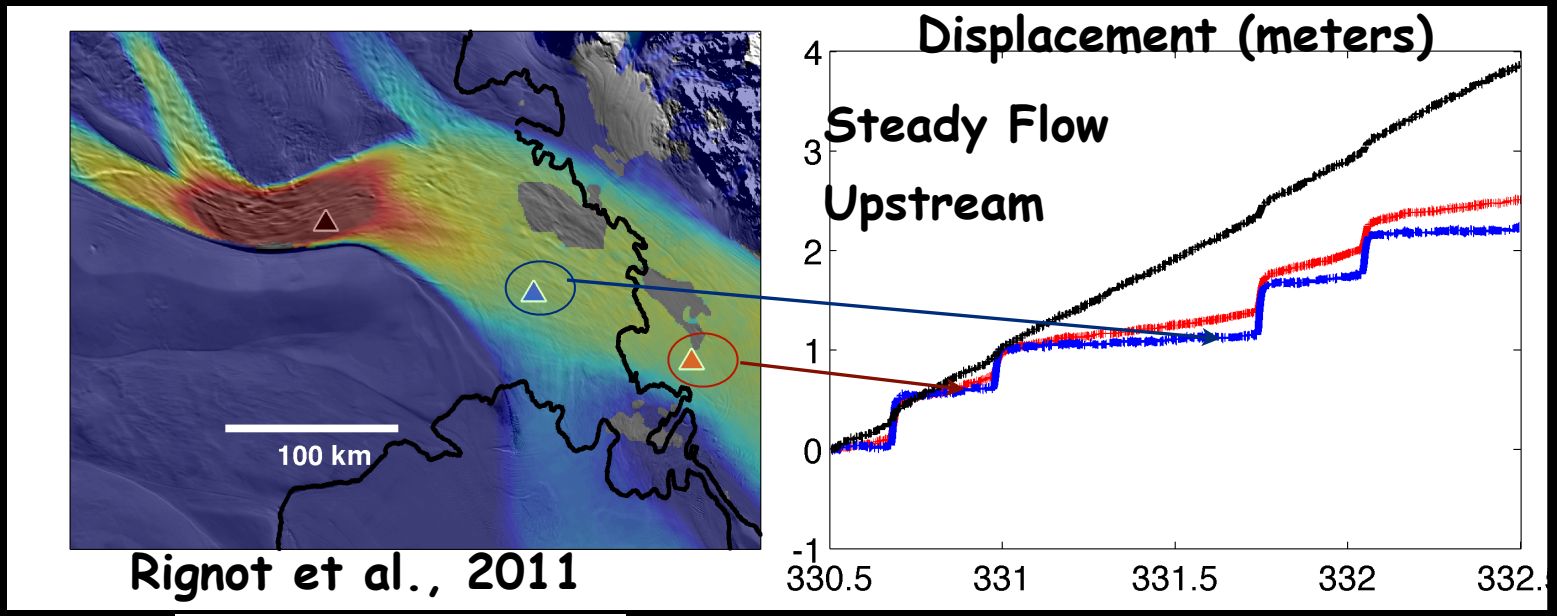
Bindschadler et al., Science 2003

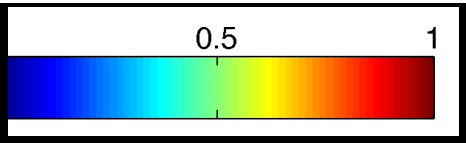
Stick-slip Area is BIG (150 km by 100 km)

Whillans Ice Stream is Sticking and Slipping

Average Velocity

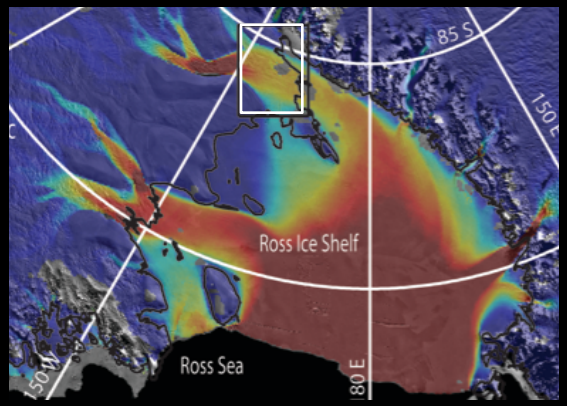
GPS time-series
for 2 Days

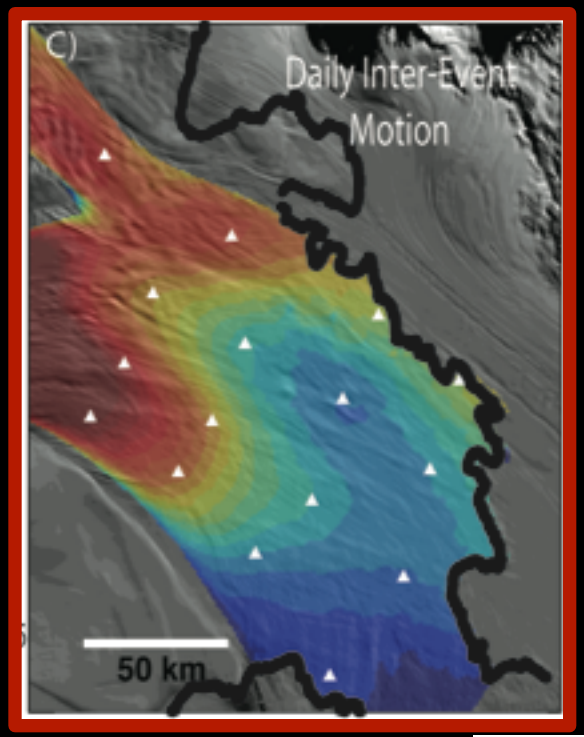


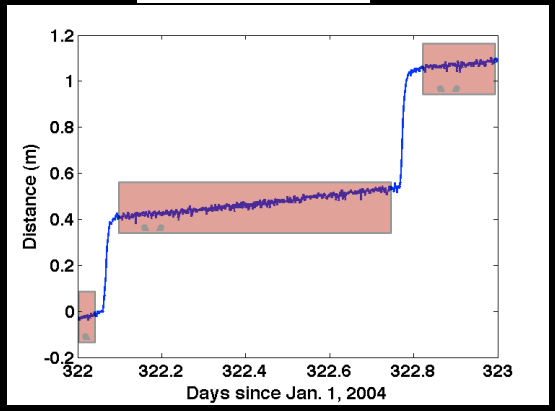


(m/day)

2004 GPS Observations







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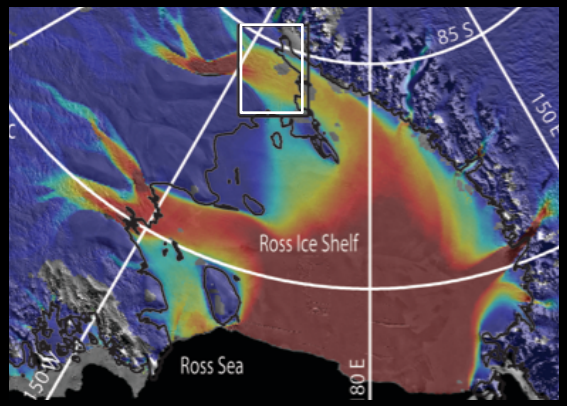
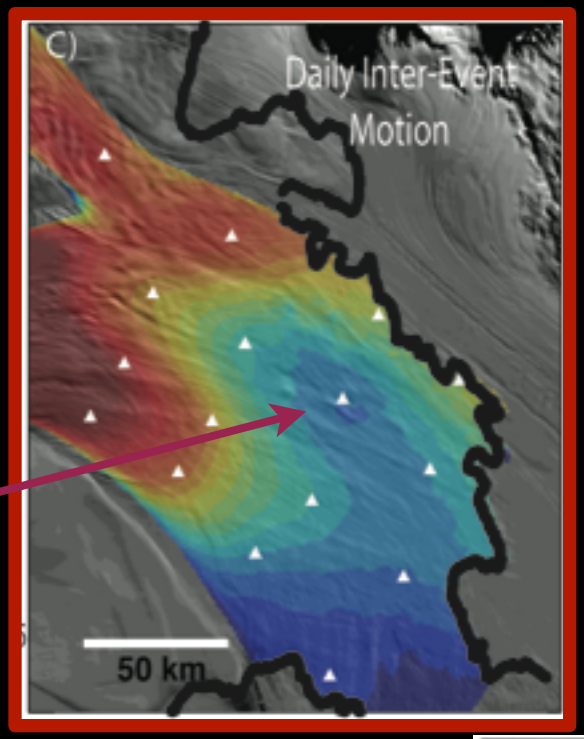
2004 GPS Observations

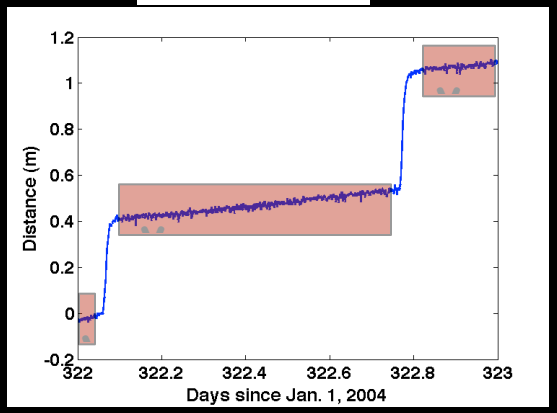




Sticky-Spot

Water is being sequestered into Subglacial Lakes

Between slip events the ice stream is flowing around "sticky-spot"



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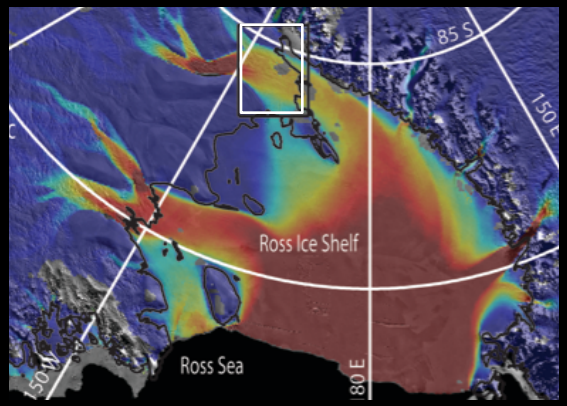
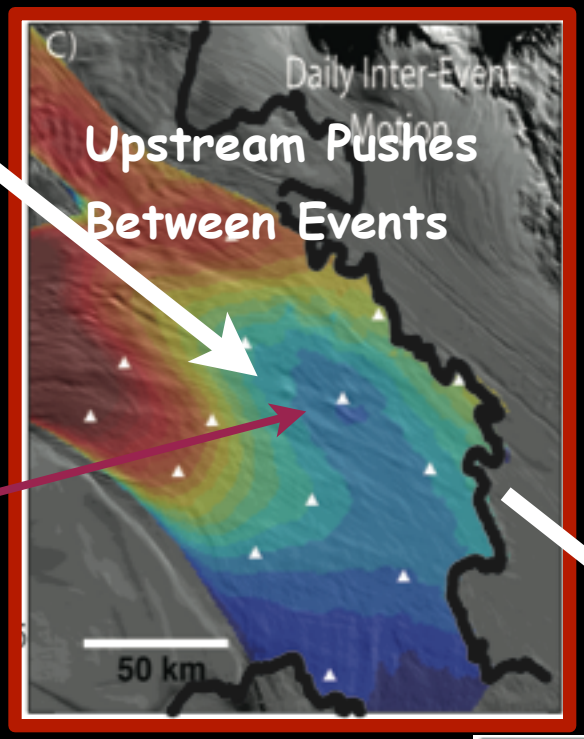
2004 GPS Observations

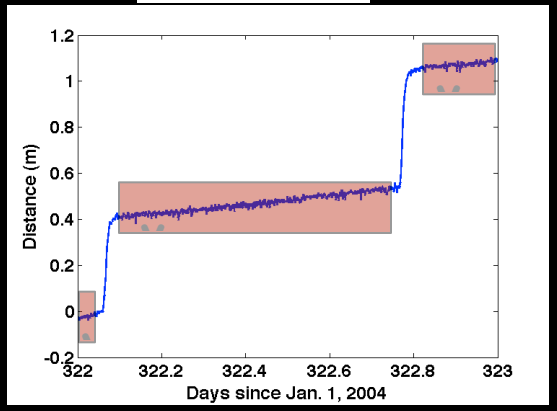




Sticky-Spot

Downstream Pulls
Between Events

Between slip events
the ice stream is flowing around
"sticky-spot"



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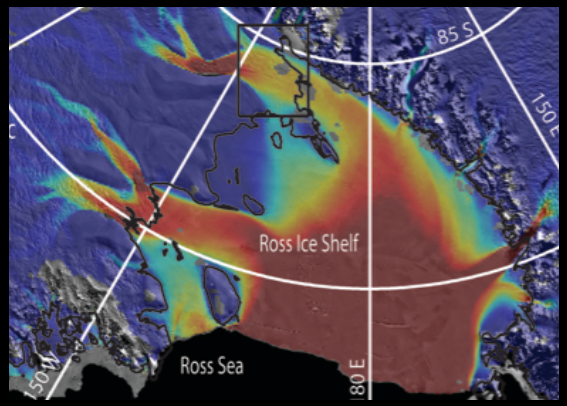
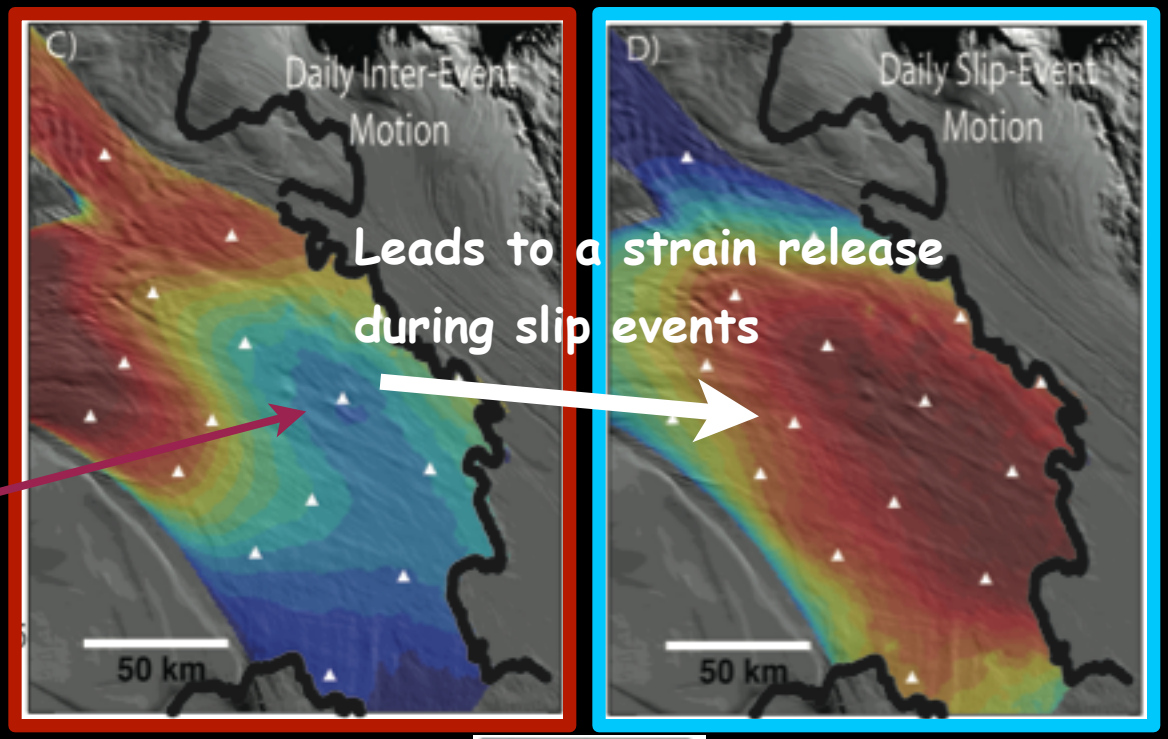


2004 GPS Observations



Between slip events
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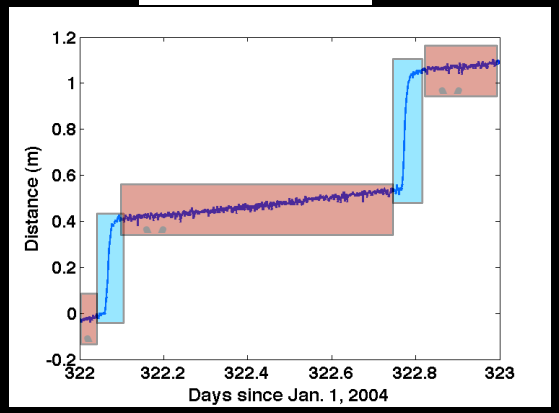

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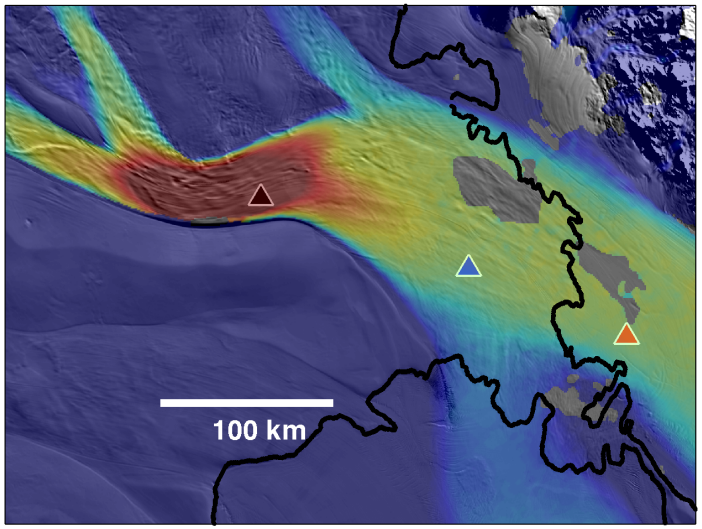
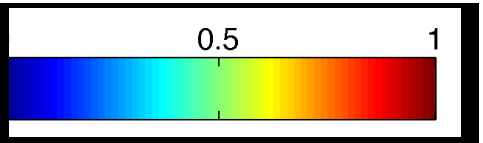
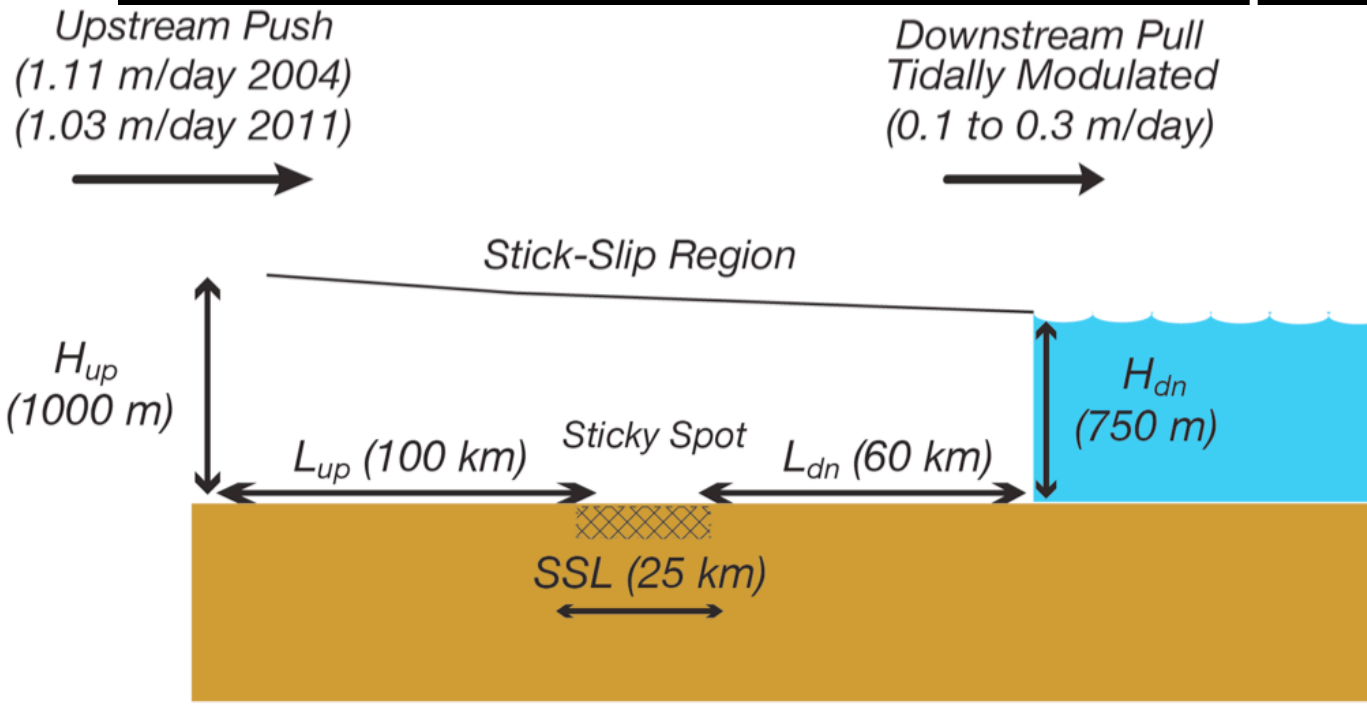


Twice Daily (almost) stick-slip events occur due to the repeated accumulation and release of elastic strain

Like an earthquake



(m/day)



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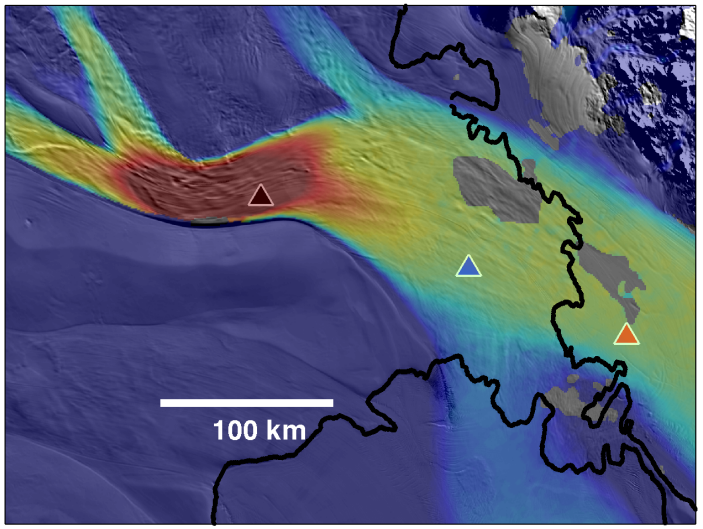
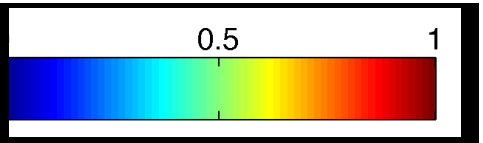


Twice Daily (almost) stick-slip events occur due to the repeated accumulation and release of elastic strain

Tidal Pacing Occurs Tidally Modulated Variation in Flow Speed near the Grounding Line

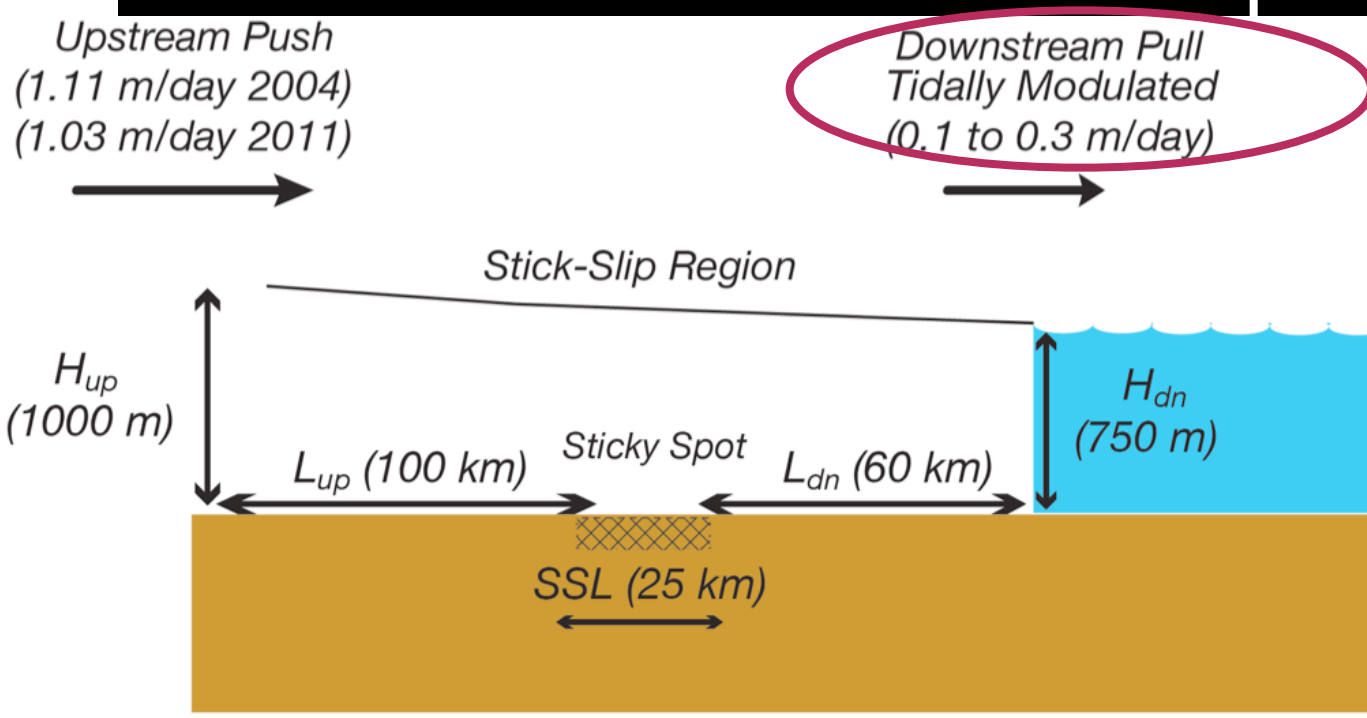


(m/day)

Visco-elastic (Maxwell)

$$\dot{\sigma} = \{\dot{\varepsilon} - A\sigma^3\}E$$

$$\tau_{sticky\ spot} = \frac{\sigma_{up}H_{up} + \sigma_{dn}H_{dn}}{L_{sticky\ spot}}$$



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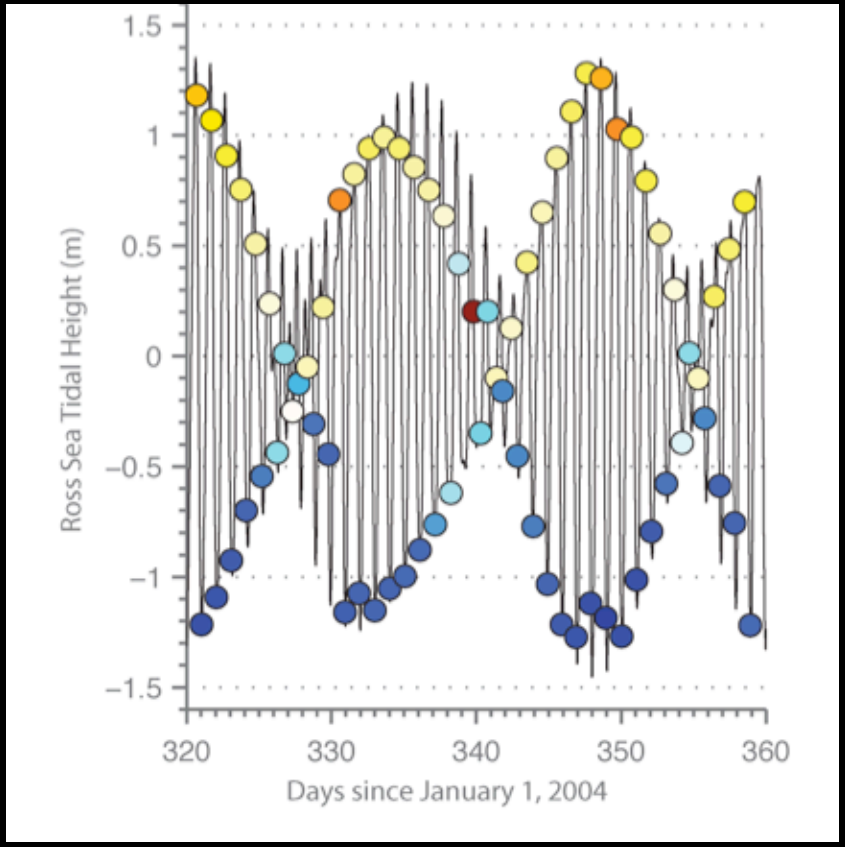
Tidal Pacing of Stick-slip Events



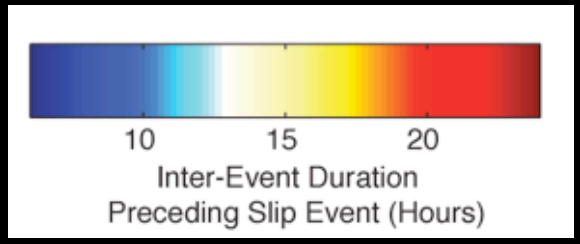
2003/2004 Observations

Two slip events per day

(99% of the time)

One Near High-Tide

One Near Low-Tide



Tides From L. Padman's Model

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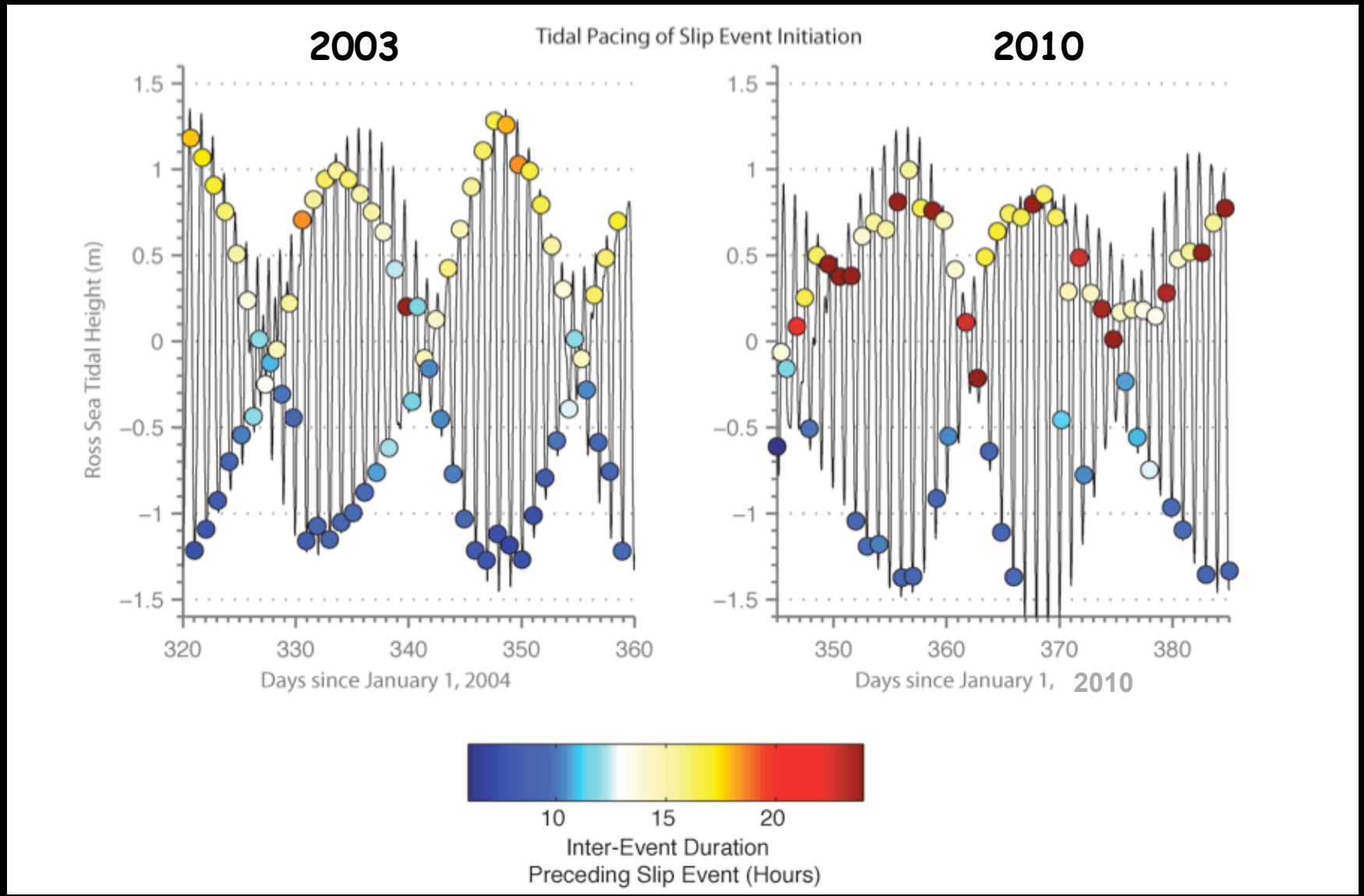

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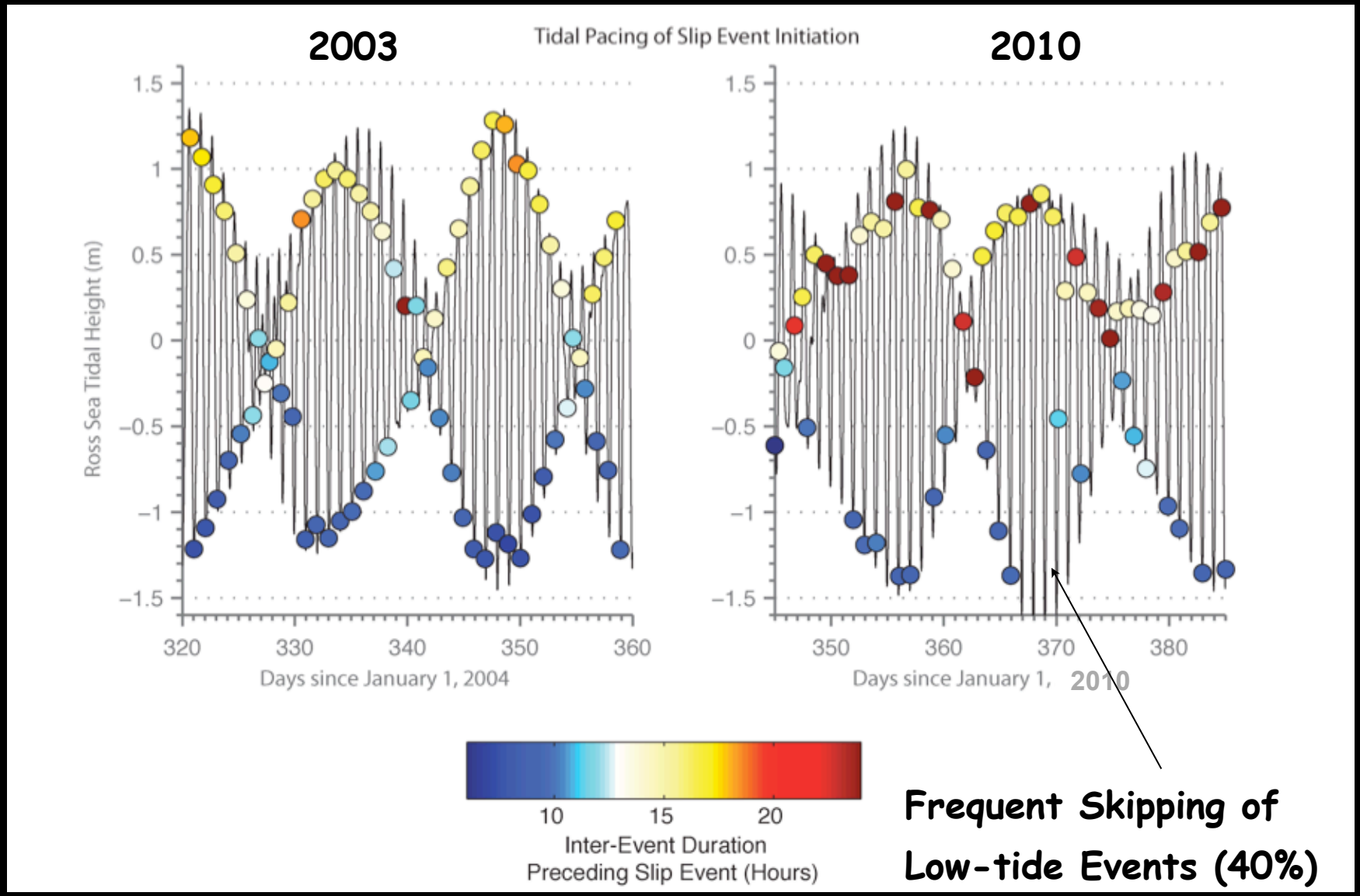
Between 2003 and 2010 Skipped Low-tide Events Became Frequent



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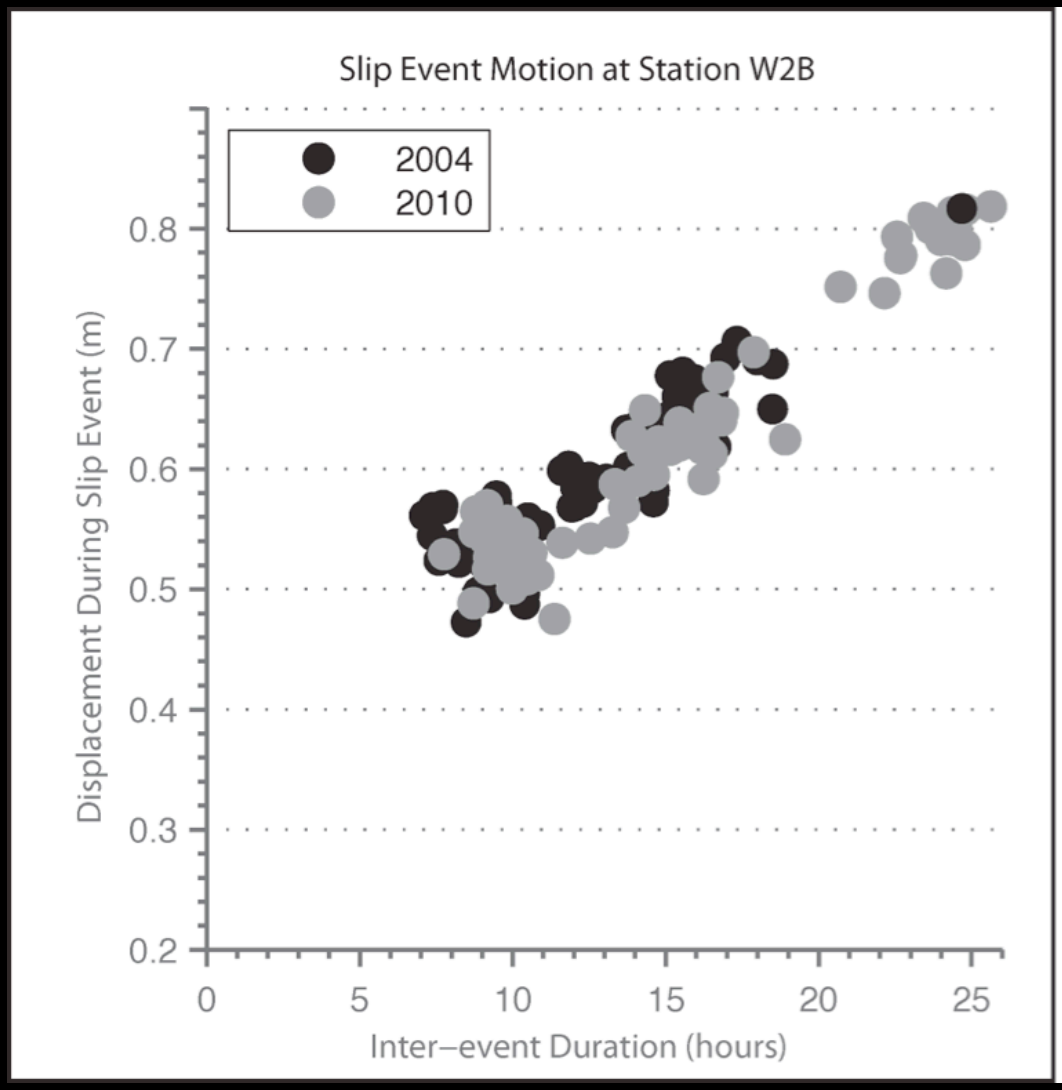

Why the ice stream cares?

Motion isn't related to driving stress but the efficient release elastic strain during slip events

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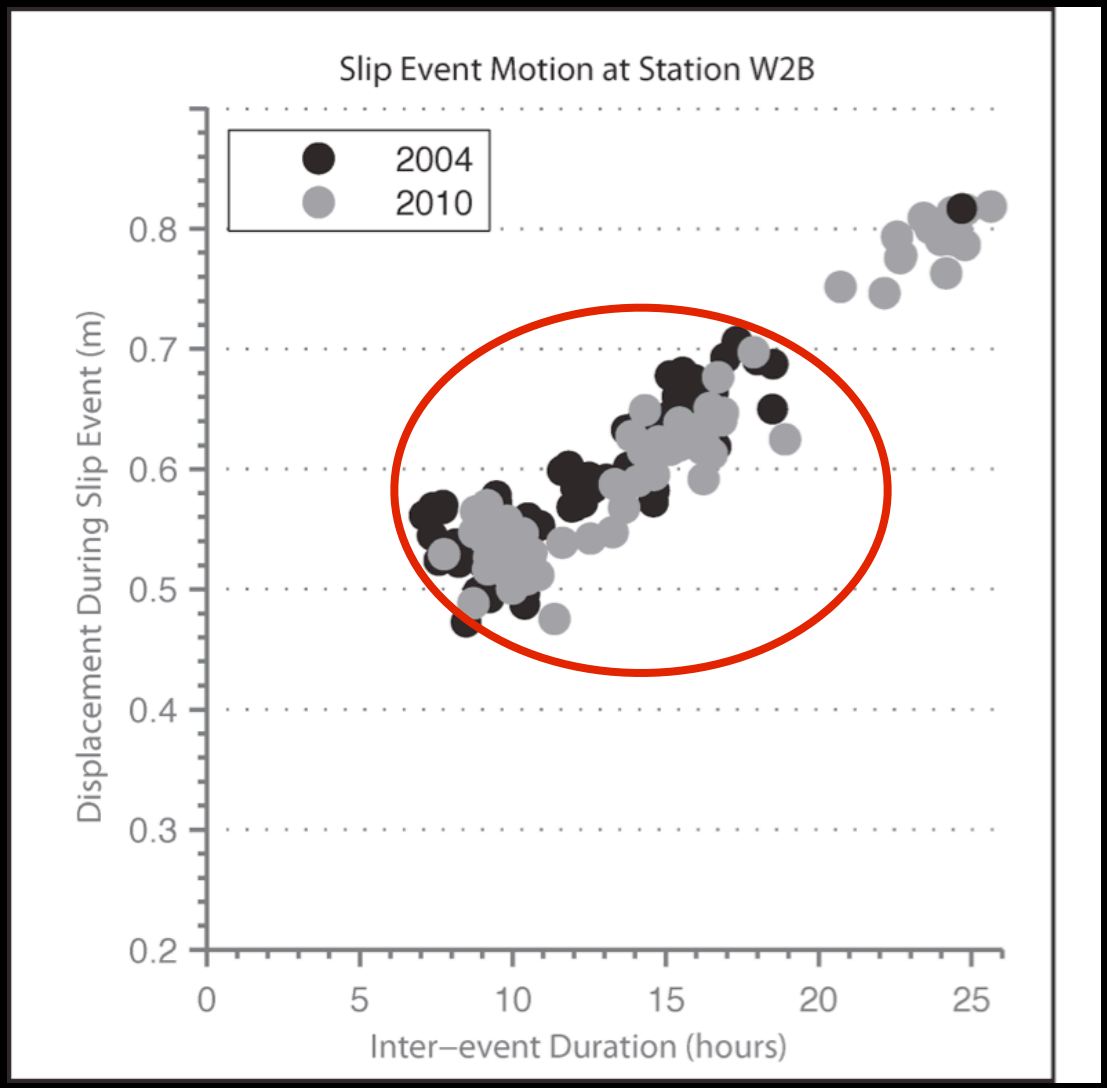

Why the ice stream cares?

When the ice stream slips twice a day it move ~1.1 meters

Variable slip is due time dependent yield stress (Winberry et al. , JGR 2009)

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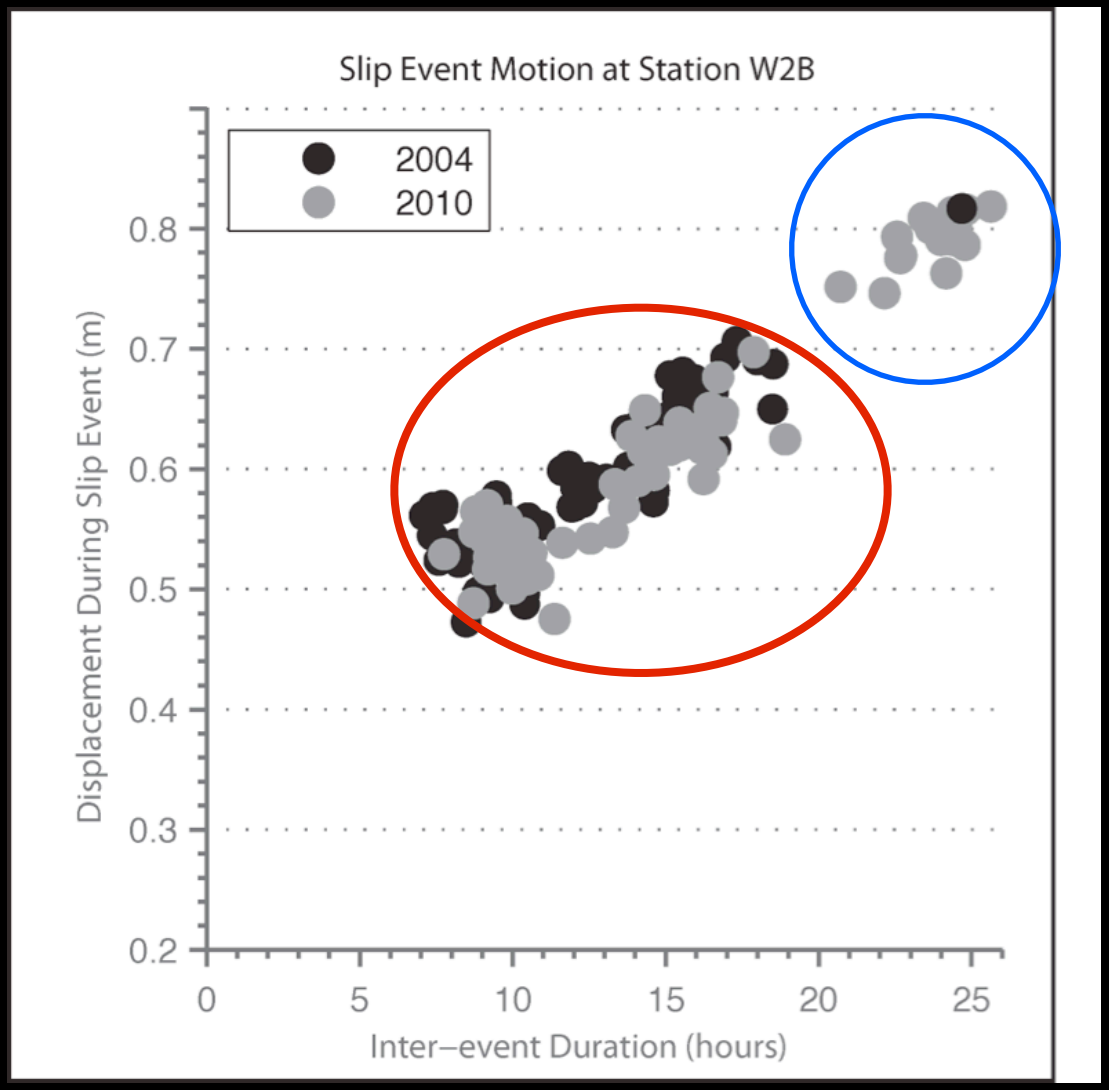

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When it slips once a day it only moves 0.8 meter per day

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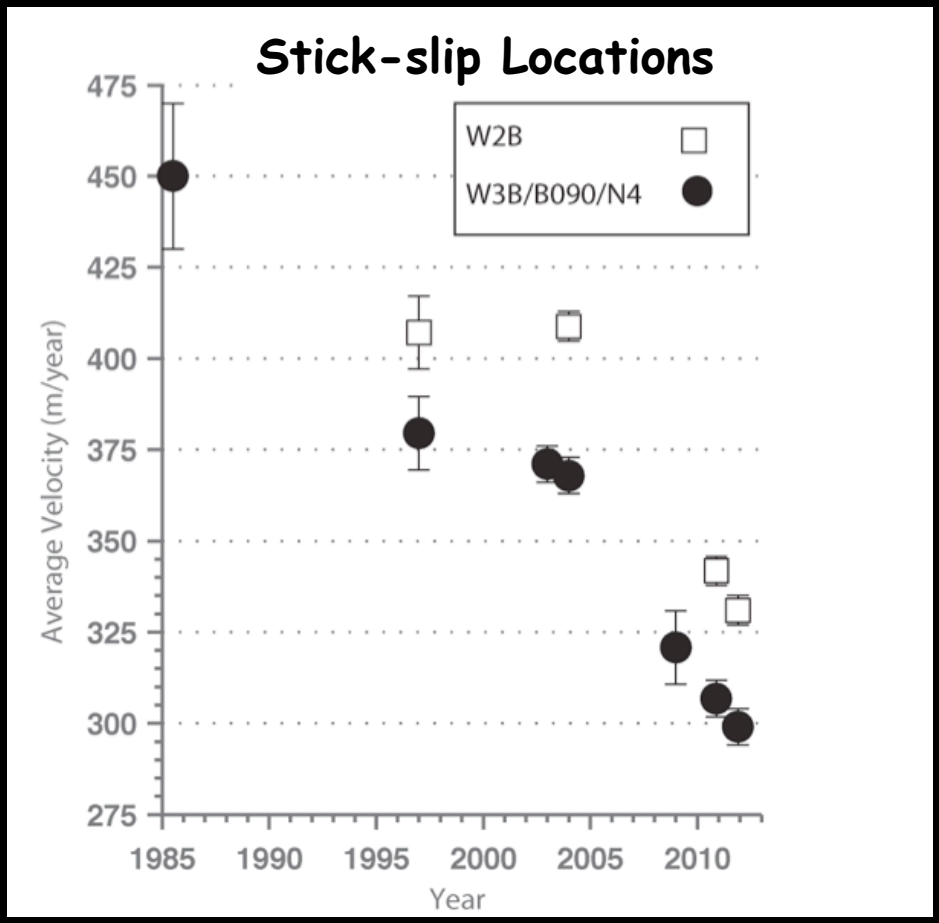
The stick-slip feedback has produced unsteady rates of deceleration



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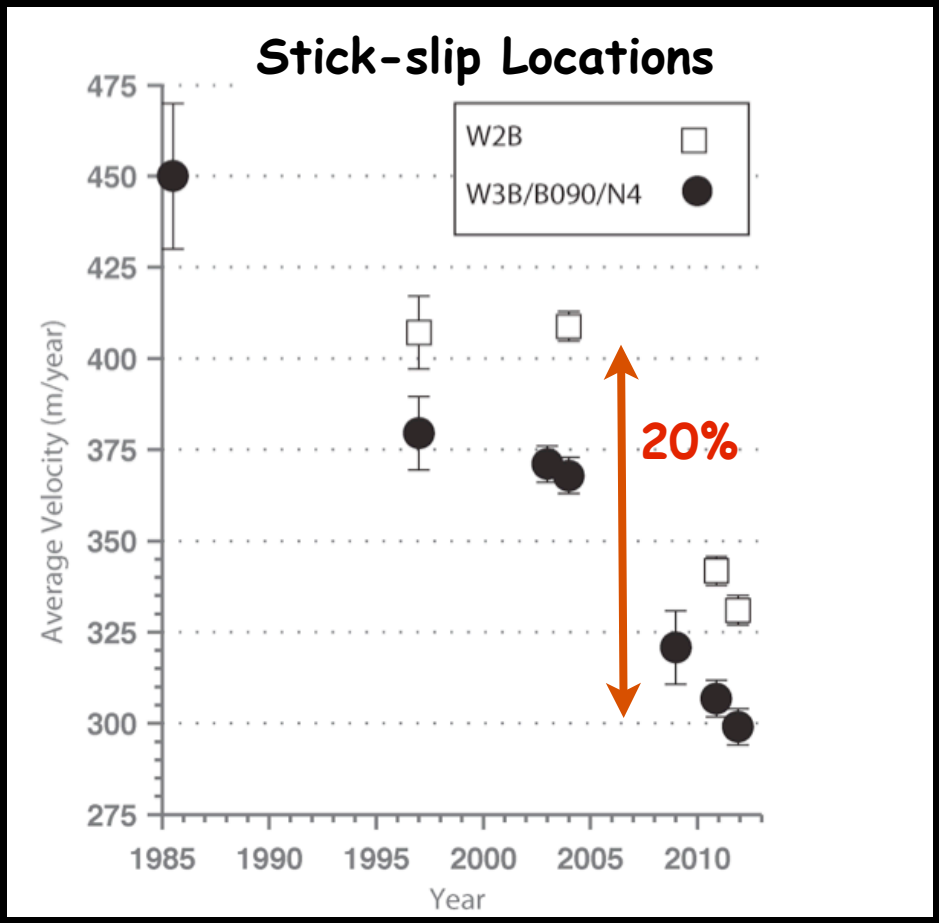

Between 2004 and 2010:

20% reduction in Flow Speed

5% reduction in the Forcing

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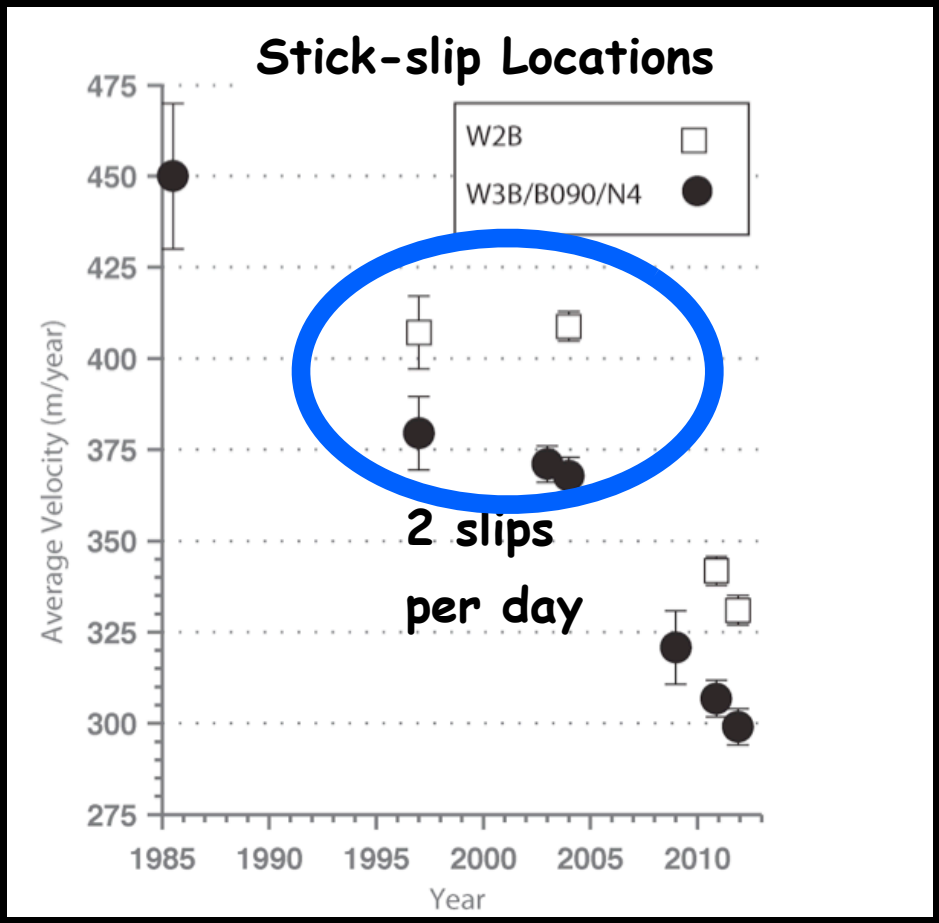
The stick-slip feedback has produced unsteady rates of deceleration



Minimal deceleration between 1997-2003

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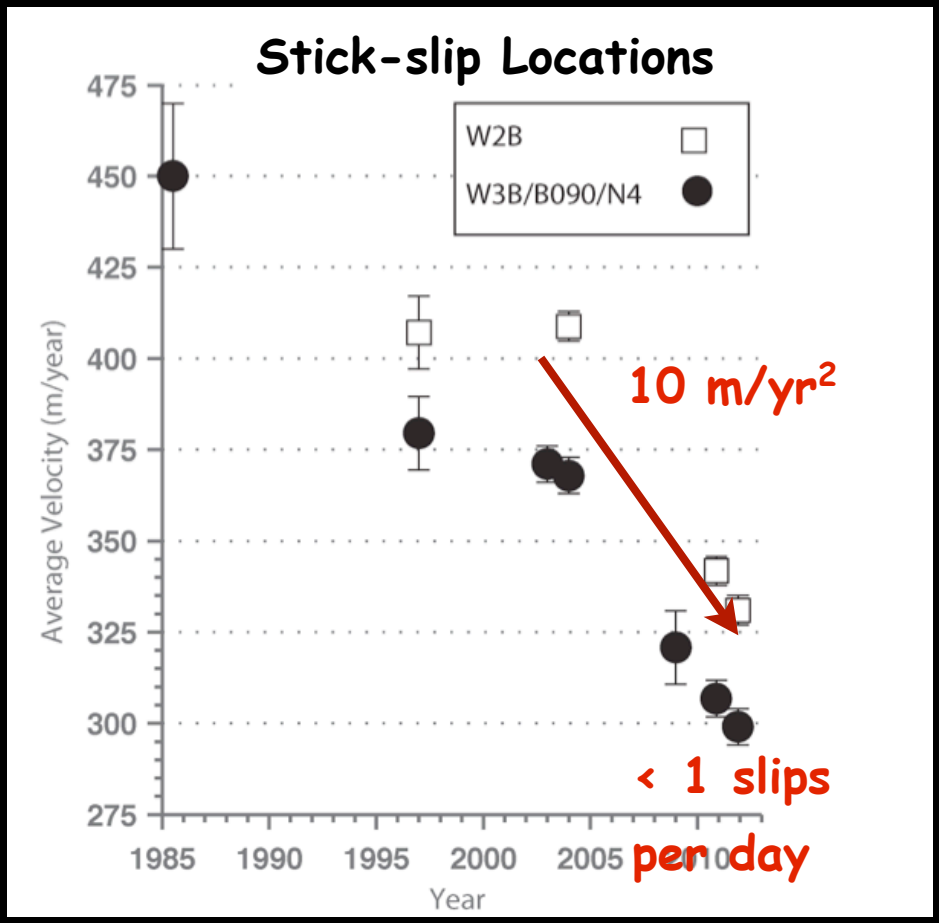
The stick-slip feedback has produced unsteady rates of deceleration



High rates of deceleration since ~2004

Due to Decreased Pushing from Upstream

Accounts for ~66% of slow-down between 2004 and 2010

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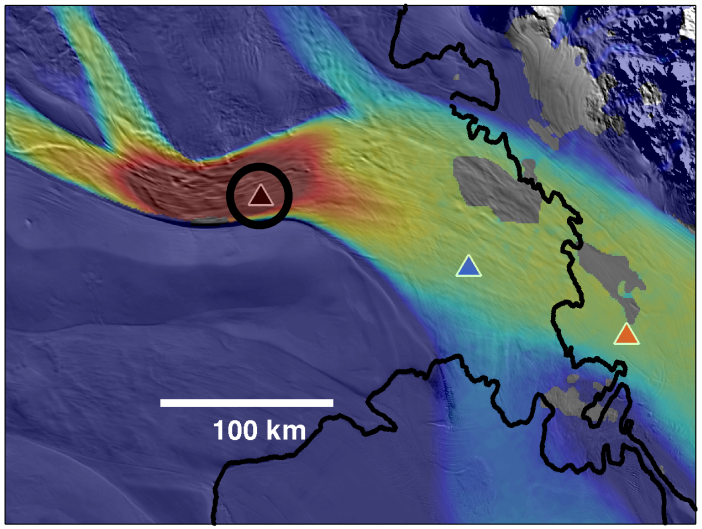
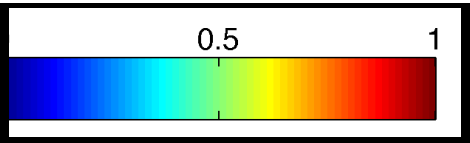


Why less Frequent slips?

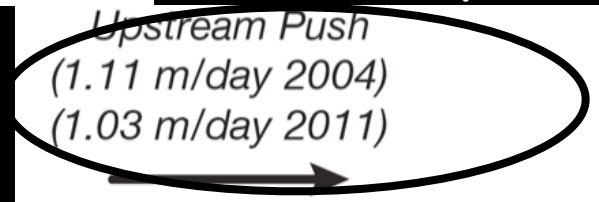
Upstream motion is slowing, decreasing loading.

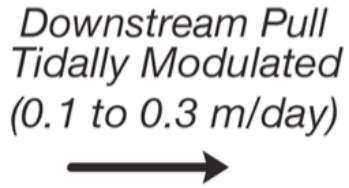
Leading to less frequent slip events.

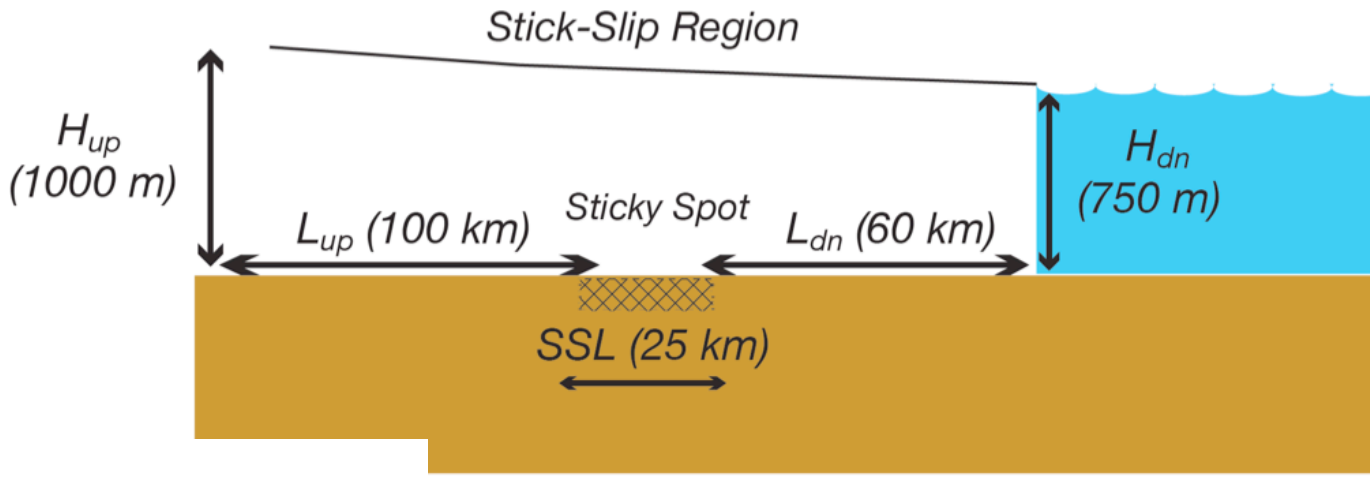
Yield strength of the bed remains unchanged (ask me if you want to see a figure)



(m/day)







$$\dot{\sigma} = \{\dot{\varepsilon} - A\sigma^3\}E$$

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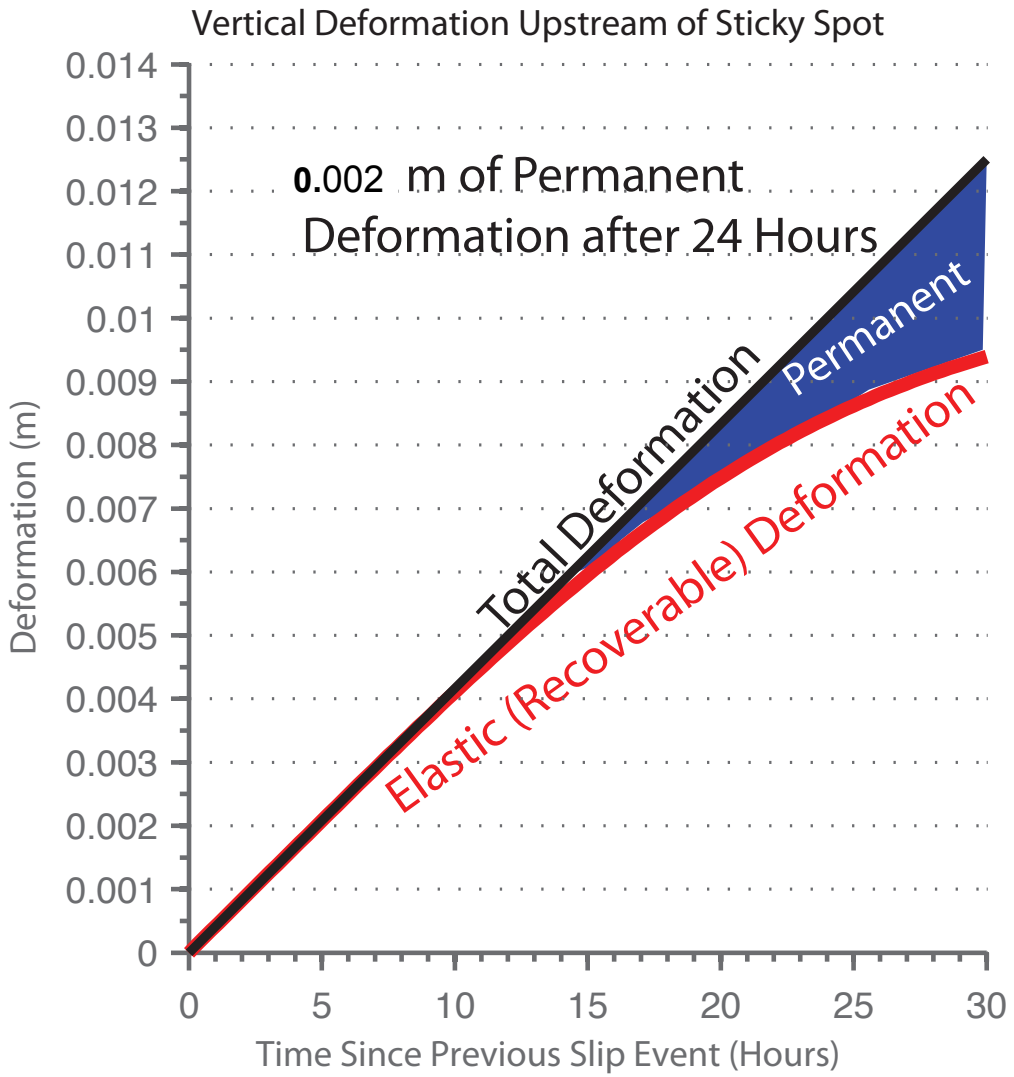
Why do slip-event days move less?

Skipped Slips lead to non-elastic deformation



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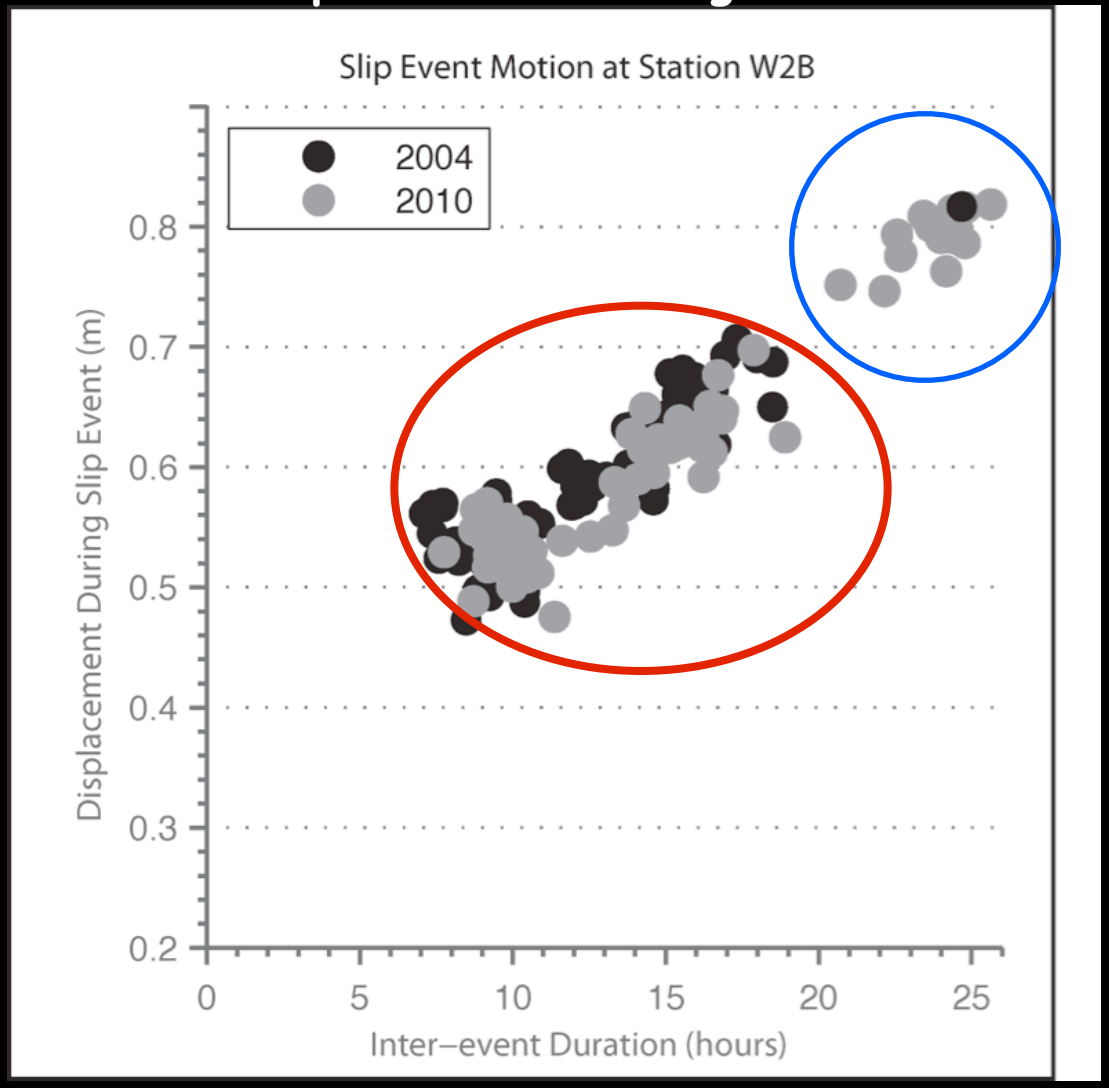
Slip events occurring after 24 hours have less elastic strain to release



Why the ice stream cares?

When the ice stream slips twice a day it move ~1.1 meters

When it slips once a day it only moves 0.8 meter per day (40% of Days)

Accounts for ~60% of slow-down between 2004 and 2010

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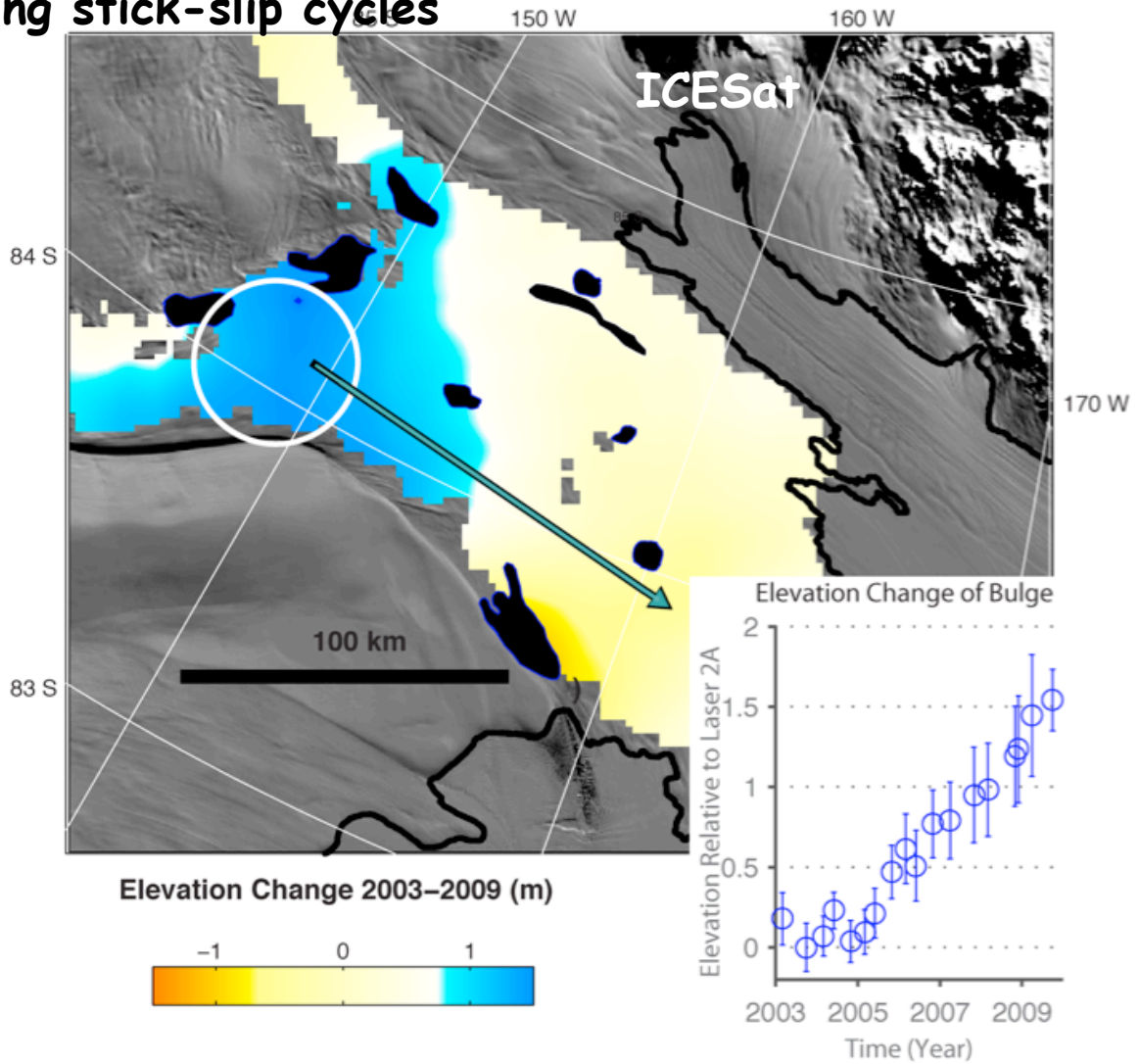
Bulge Forming Upstream of the Stick-slip Region as a result from the increased permanent deformation during stick-slip cycles



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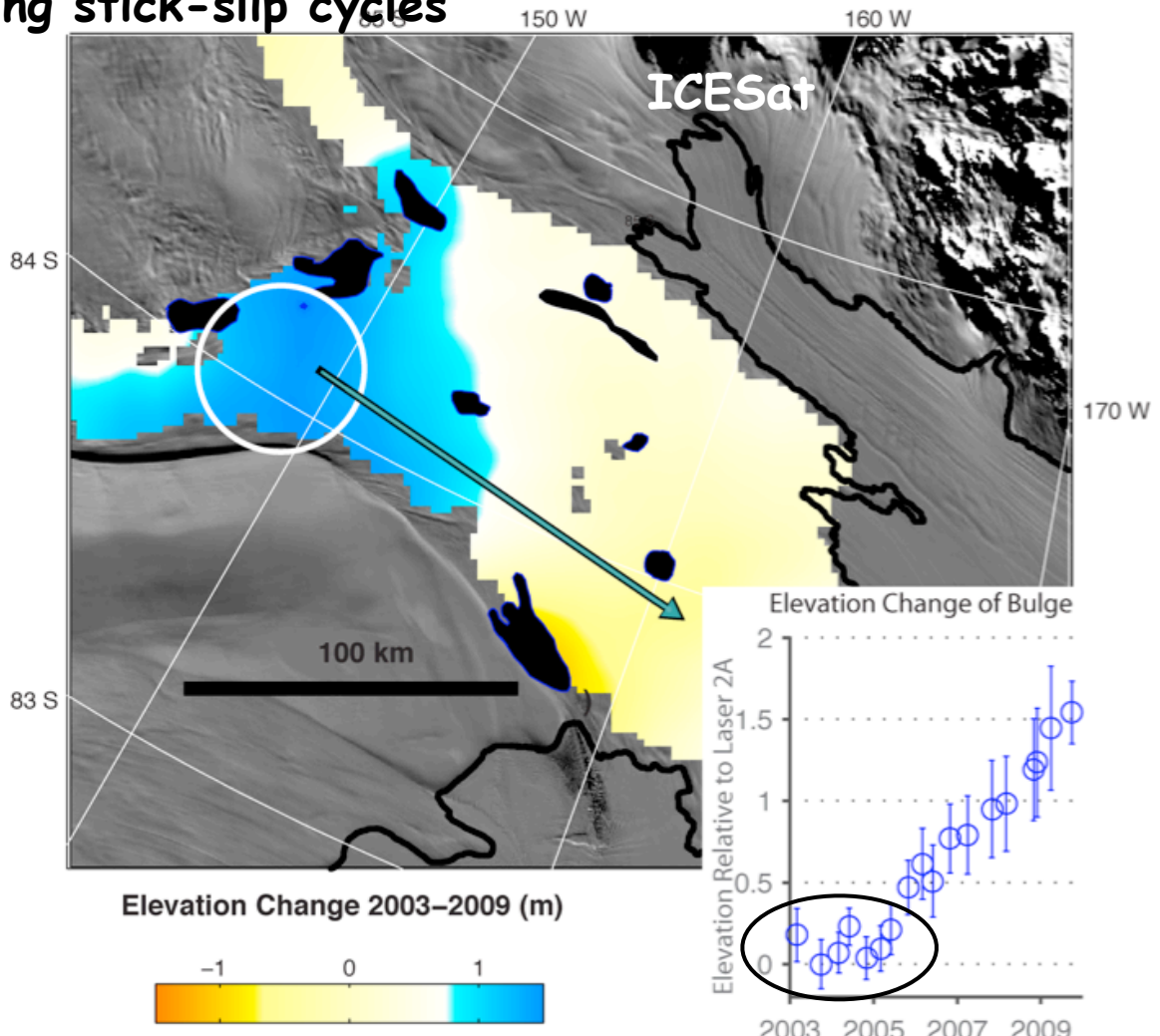

2 Slips per Day No Thickening

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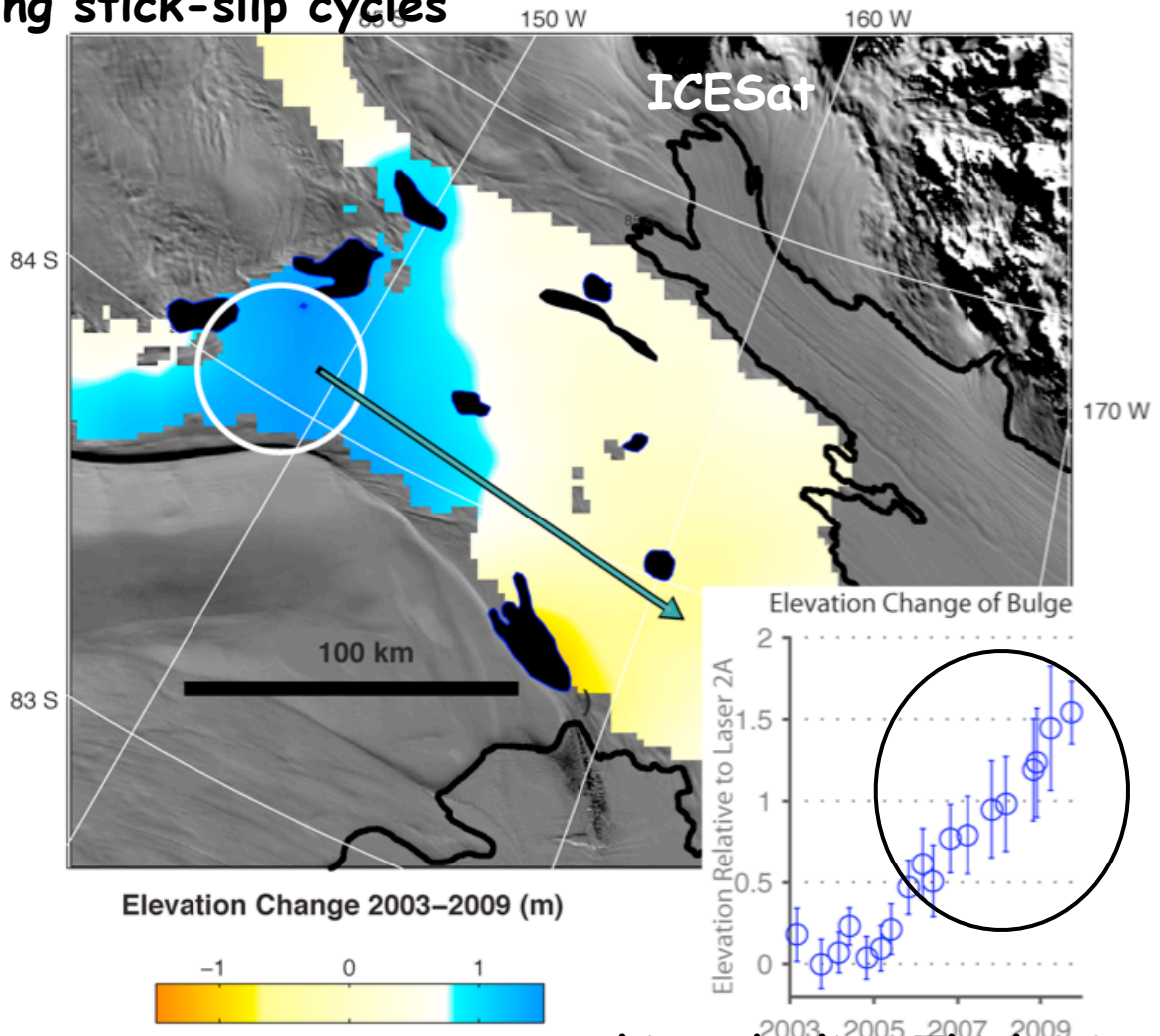

Skipped Slips Thickening

150 Days (~0.002 m/skipped Slip) =~0.3 m.year

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Ice Sheets React Over a Wide Range of Time-Scales

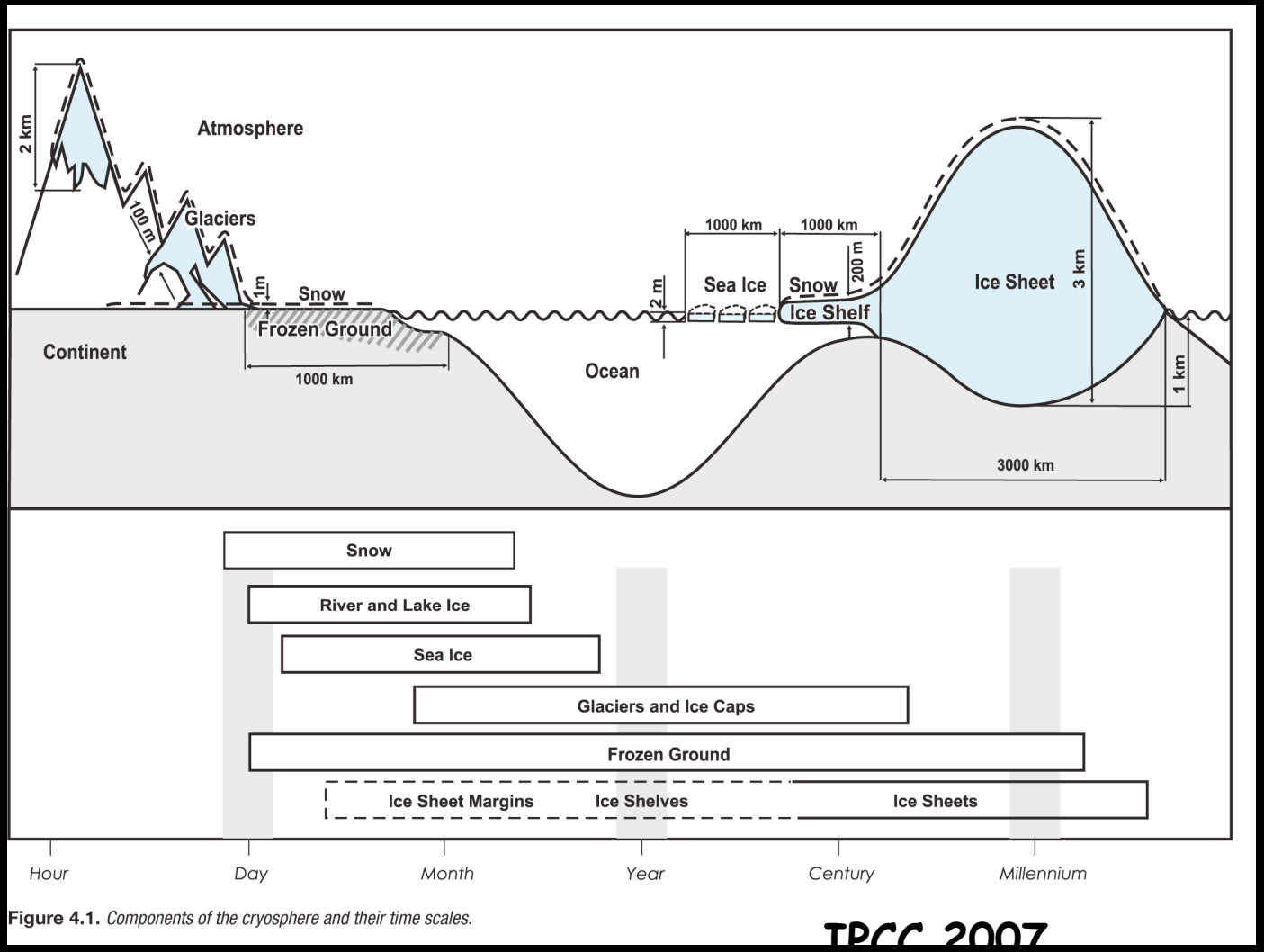
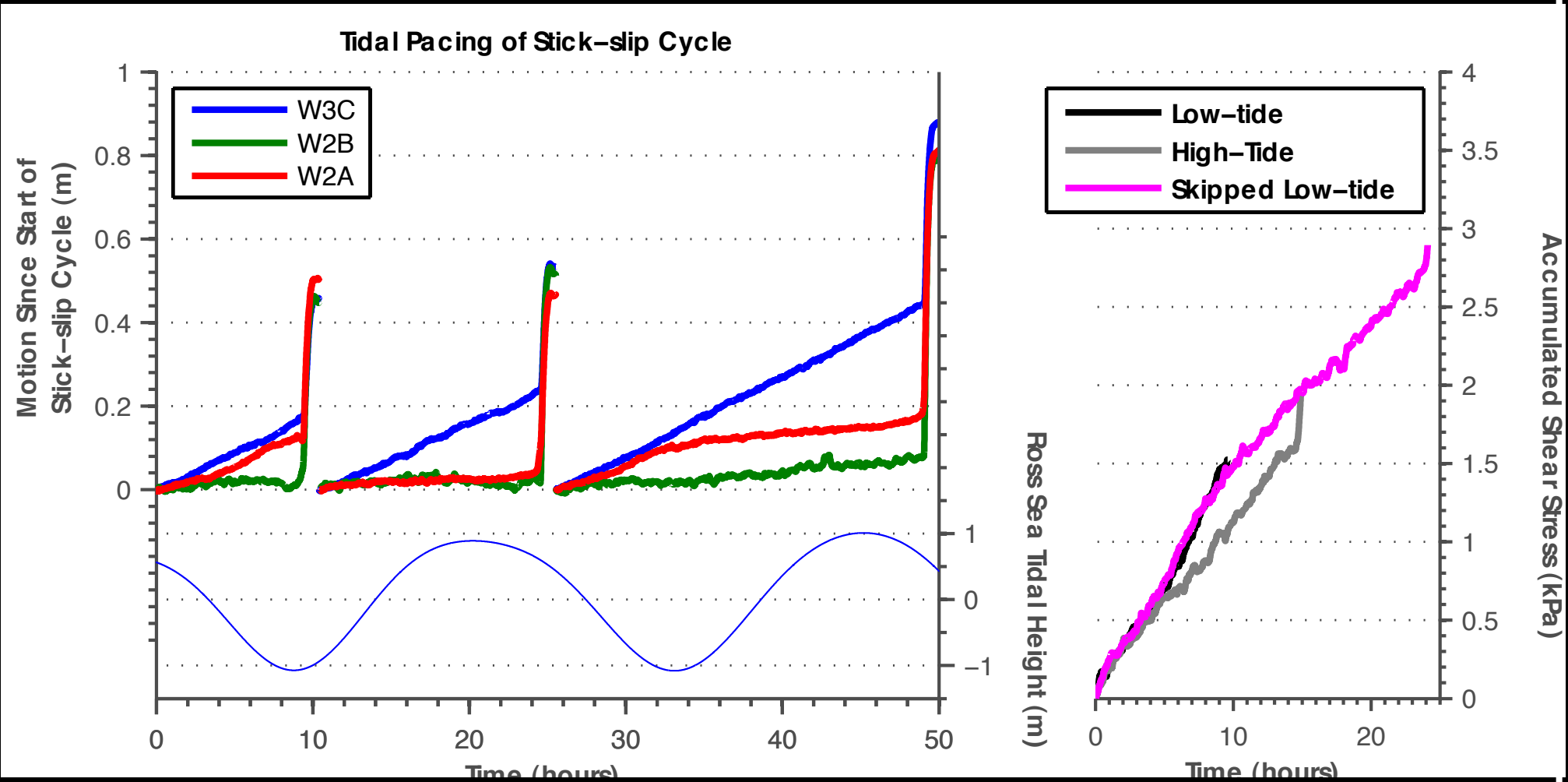


Figure 4.1. *Components of the cryosphere and their time scales.*

IPCC 2007

Short time-scale physics (stick-slip, calving) may be important to understanding long-term behavior



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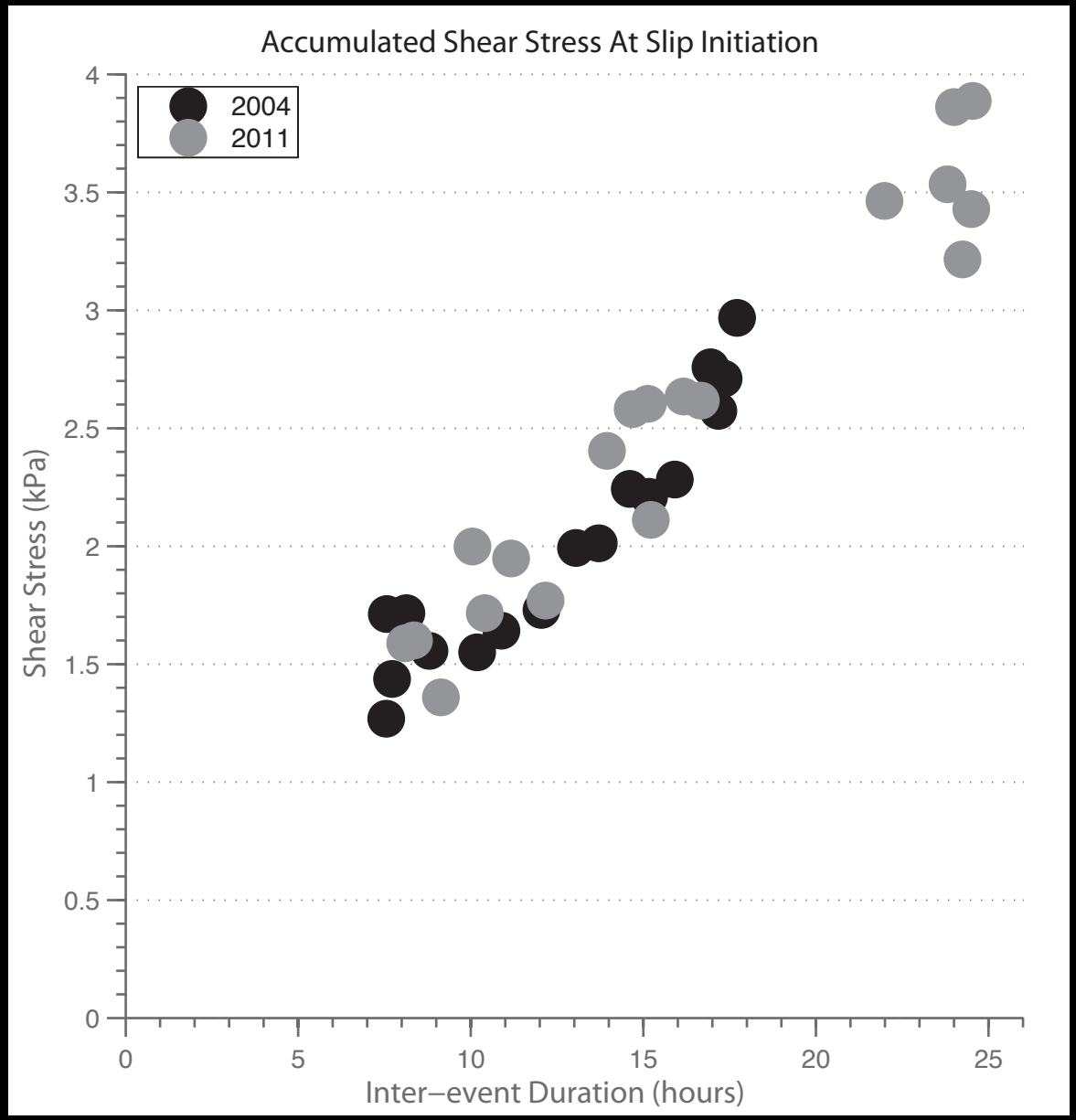
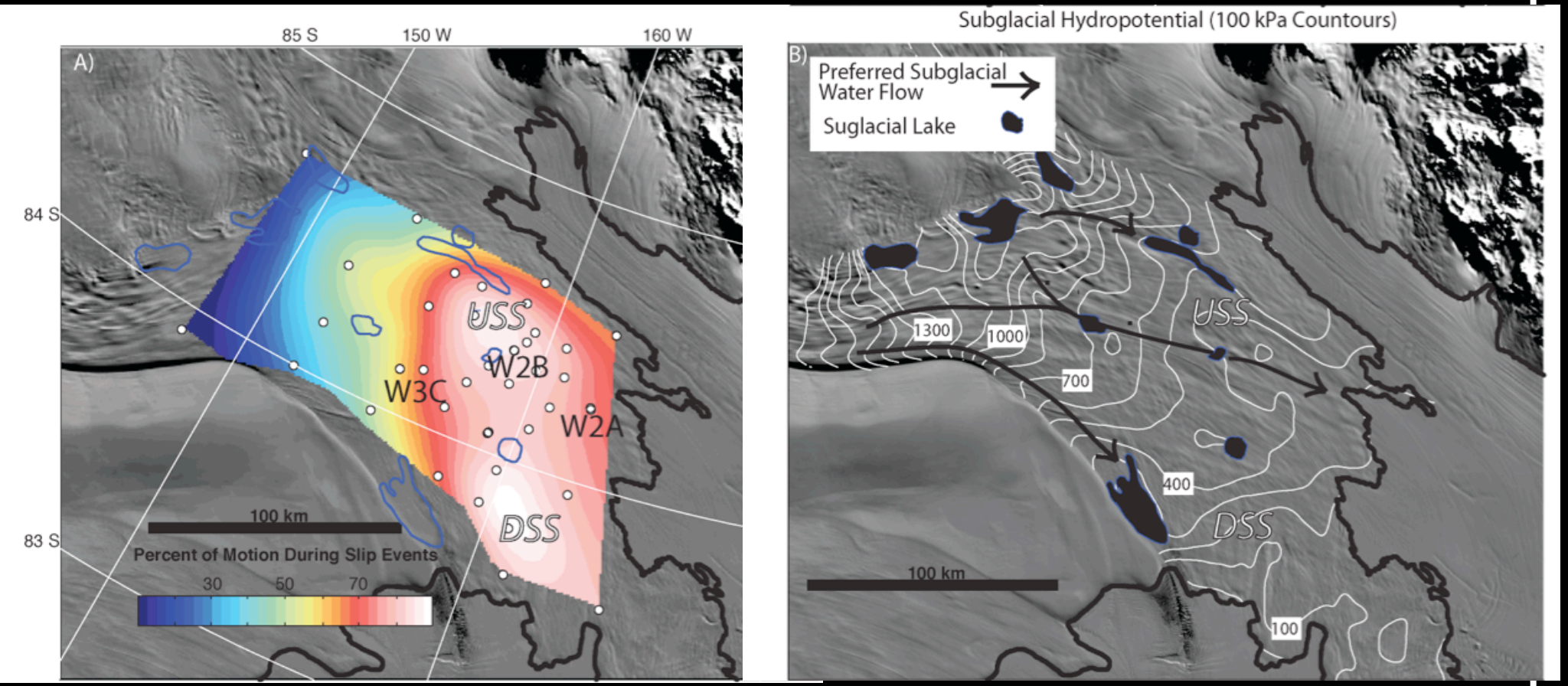

Accumulated Shear Stress At Slip Initiation
2004
2011
Shear Stress (kPa)
Inter−event Duration (hours)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25



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