Tidal forcing of seismicity and slip, ice streams B & C

Tides Project Team

RB Alley, S Anandakrishnan,
RA Bindschadler, S.Das, I Joughin, MA King,
LE Peters, DE Voigt, JP Winberry

Funded by NSF-OPP.
Thanks to Mark Fahnestock for loan of GSP.

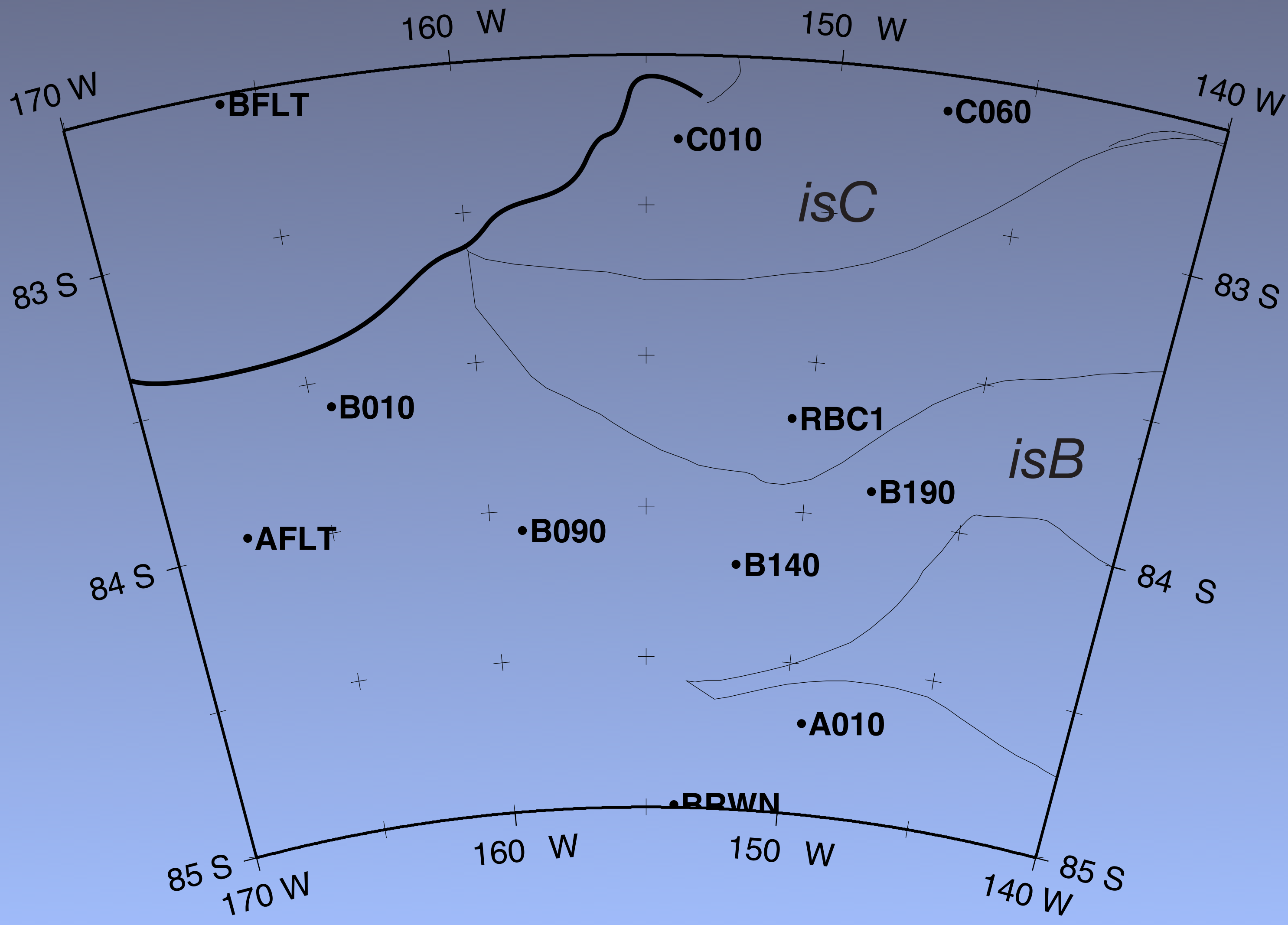
Tides, Slip, Seismics (prior work)

- Tides in the Ross Ice Shelf control flow of the ice plains of ice streams B, D, and E.
  - Flow is stick-slip on B, smoothly modulated on D/E
- These same tides control basal seismicity of ice stream C.
  - The seismicity was assumed a proxy for slip, lacking the ability to measure flow variations isC.
- Tide phase crucial (high vs. low)
- Tide amplitude effects unknown (spring vs. neap)

Seismicity and Slip relationship hypothesized.

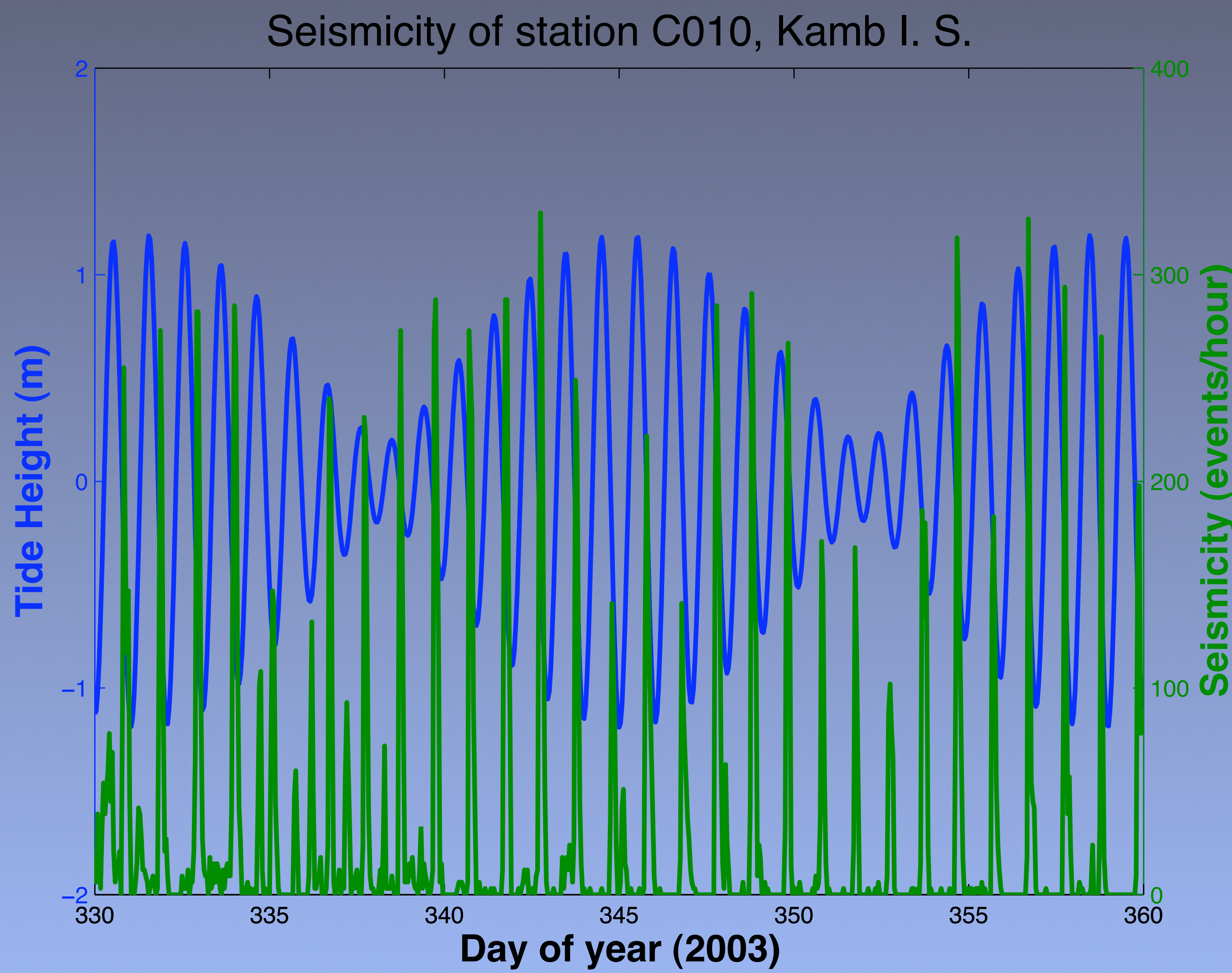
- However, this relationship was not confirmed.
- Prior work on isC recorded seismicity but could not record slip (flow speeds too low)
- Prior work on D recorded slip but not seismicity (seismometers too far away, at Siple Dome and Ridge DE, not on D itself)
- Prior work on B was GPS only, so no seismometers used
  - » (aka, “aseismic Bob”), inside joke!

Map of study region

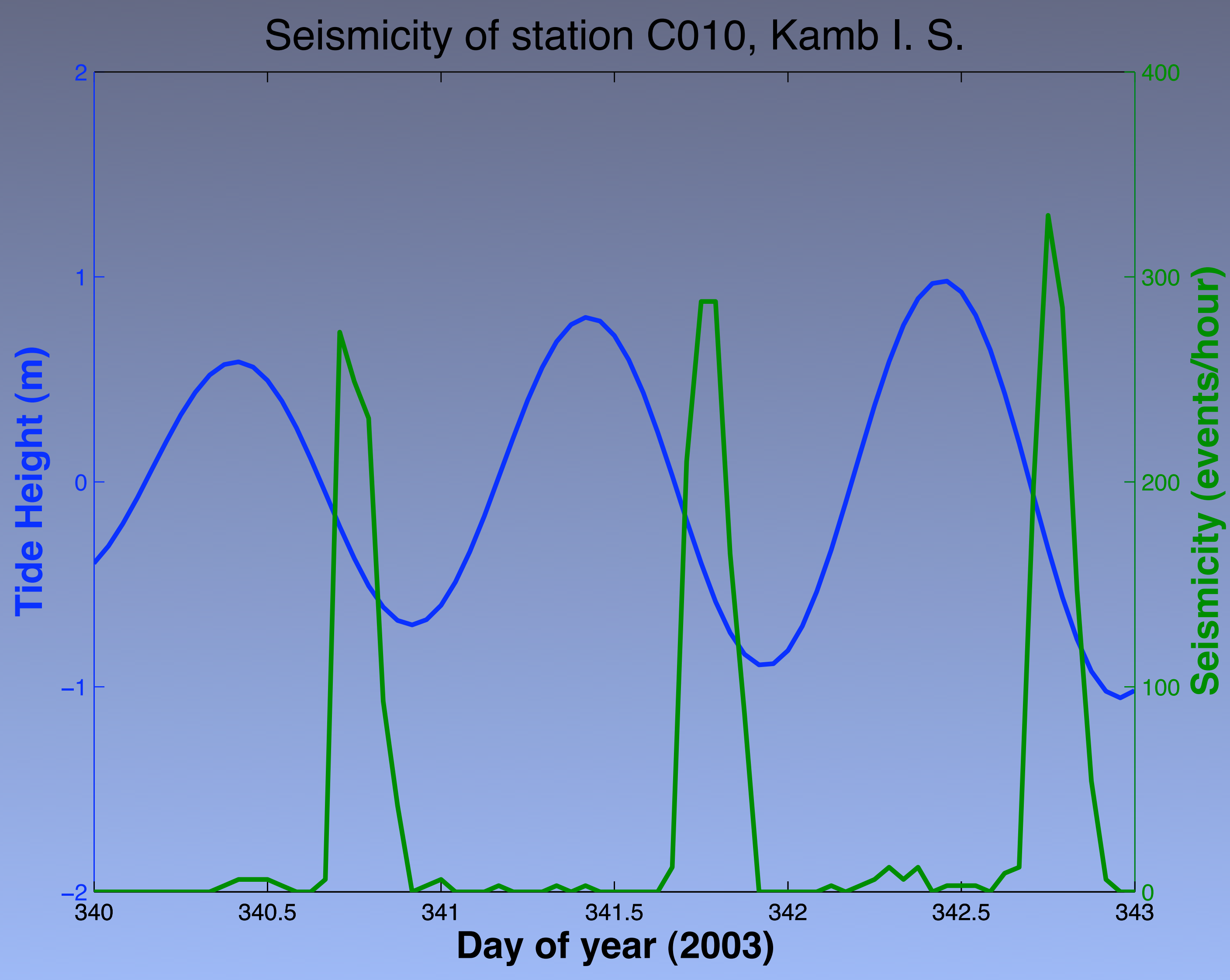


Combined Seismic/Slip experiment

- Stations C10, B10, B90, B140 had both seismometers and GPS receivers.
  - GPS receivers measure position every 5 min.
  - Seismometers trigger on seismic activity.
- Station BFLT measures the tide directly.



Seismicity of station C010, Kamb I. S.
Tide Height (m)
2
1
0
−1
−2
Seismicity (events/hour)
400
300
200
100
0
330
335
340
345
350
355
360
Day of year (2003)



Seismicity of station C010, Kamb I. S.
Tide Height (m)
Seismicity (events/hour)
Day of year (2003)
2
1
0
−1
−2
400
300
200
100
0
340
340.5
341
341.5
342
342.5
343

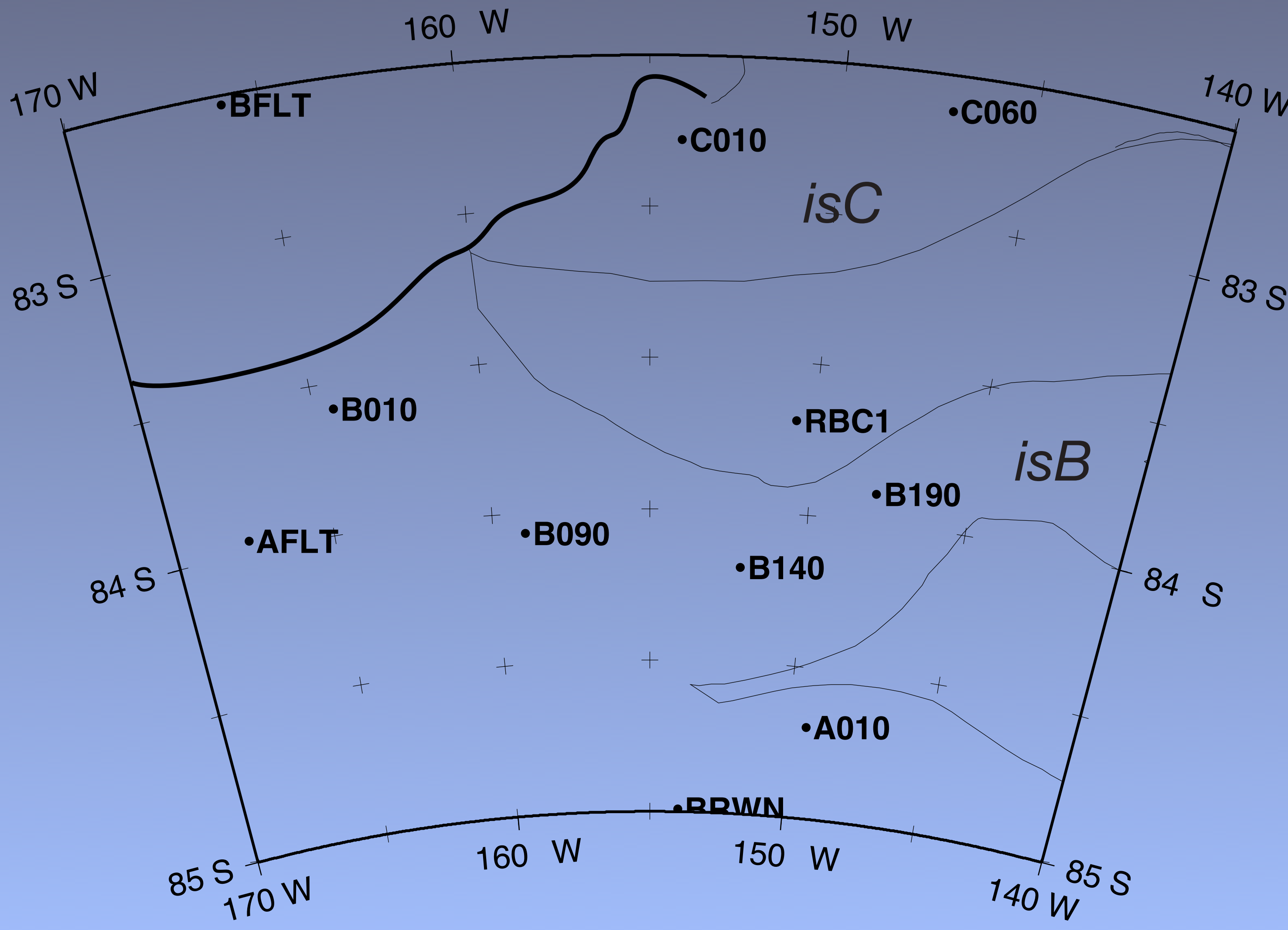
Ice stream C results compared to prior results

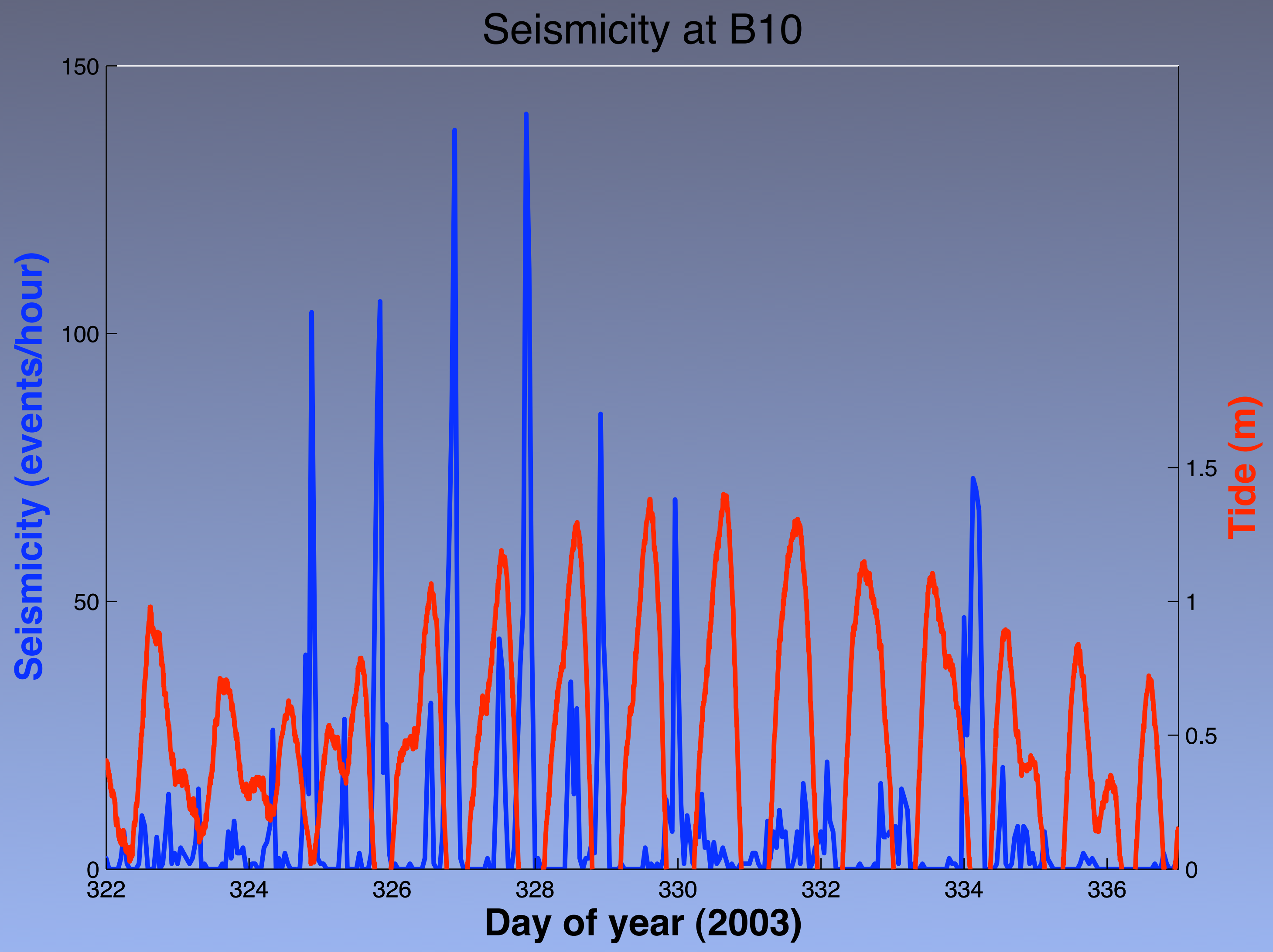
- Prior work used modeled tide and tide extrapolated from measurements taken decades earlier.
- New results agree with earlier conclusions
  - seismicity is at falling or low tide (*phase matters)*
  - Tide amplitude effect inconclusive (*spring/neap)*
  - Slip vs. seismicity still inconclusive (*isC too slow)*

New results from isB (Whillans)

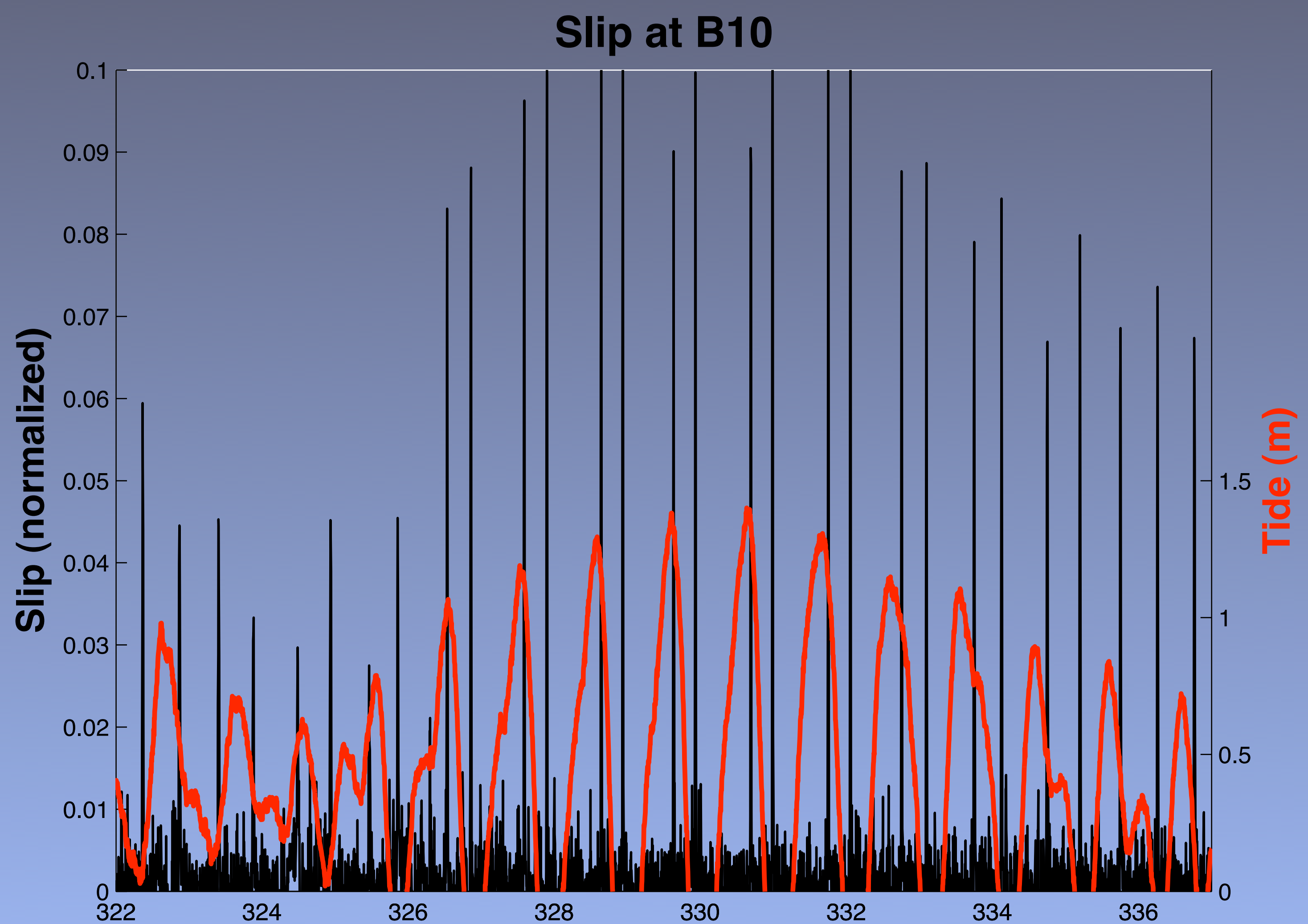
- Comparison of seismicity and slip.
- Comparison of relative importance of tide phase *(high vs. low)* and tide amplitude *(spring vs. neap)*.

Map of study region

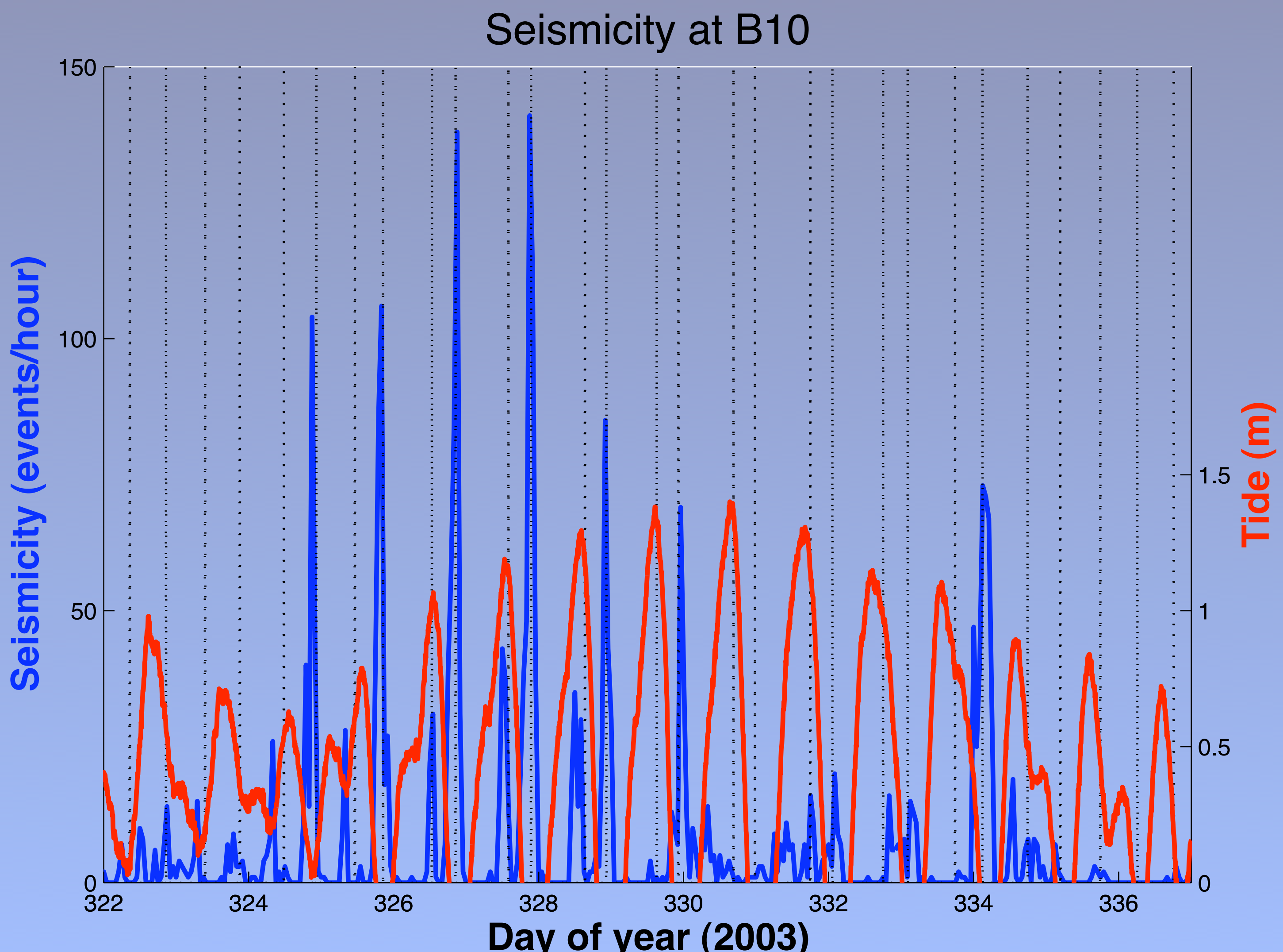




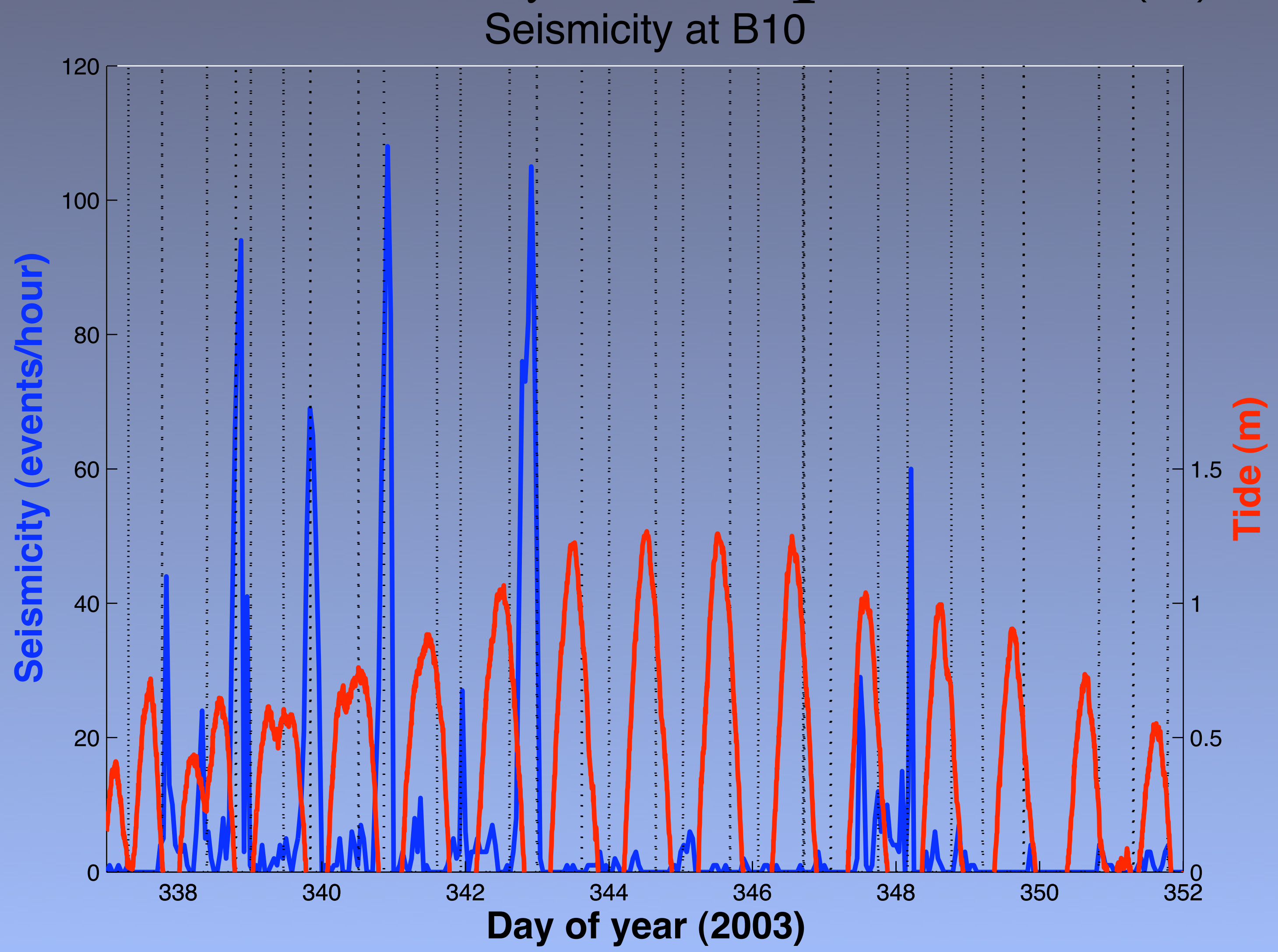
Seismicity at B10
150
100
50
0
322
324
326
328
330
332
334
336
Day of year (2003)
Seismicity (events/hour)
Tide (m)
1.5
1
0.5
0


Slip at B10
Slip (normalized)
Tide (m)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
322
324
326
328
330
332
334
336
1.5
1
0.5
0

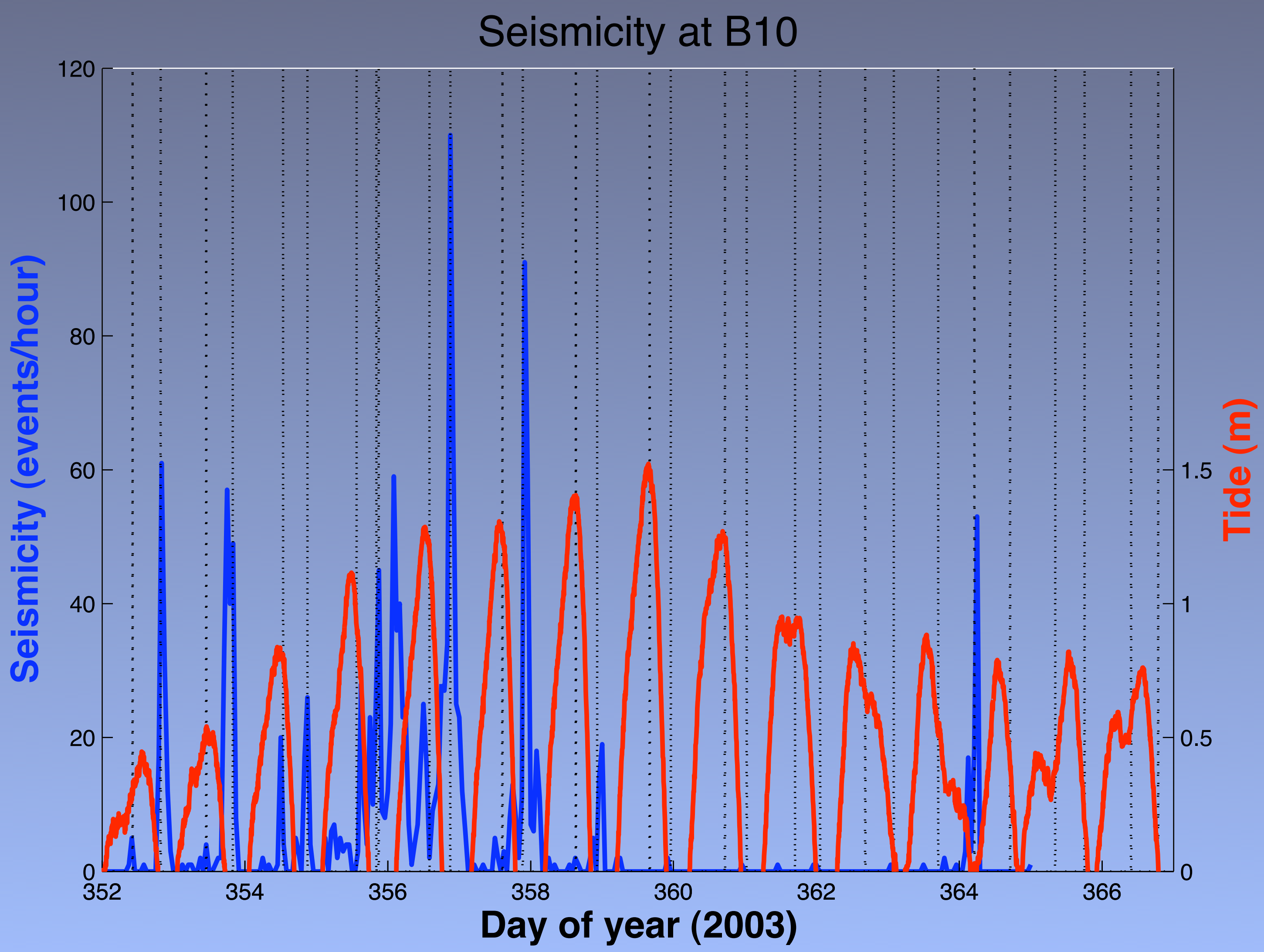
Seismicity + Slip-times (1)



Seismicity + Slip-times (2)



Seismicity + Slip-times (3)



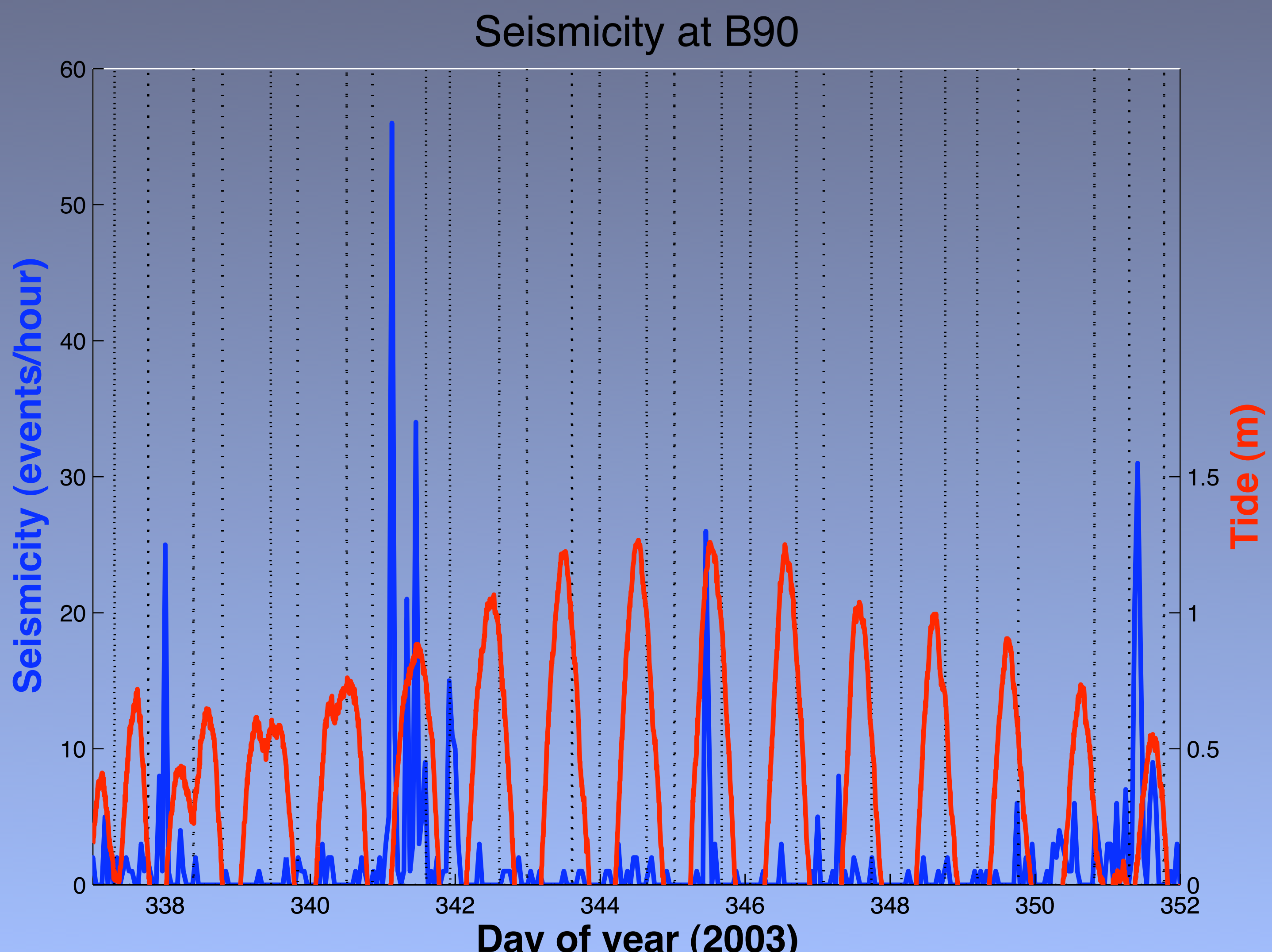
Observations

- Two slip events per tidal cycle
  - One at high tide (or soon after), one at low tide (or just before)
  - Neap tide has less-regular slip
- Seismicity is almost always associated with the 2nd slip event.
- Low (non-zero) level of seismicity throughout the day

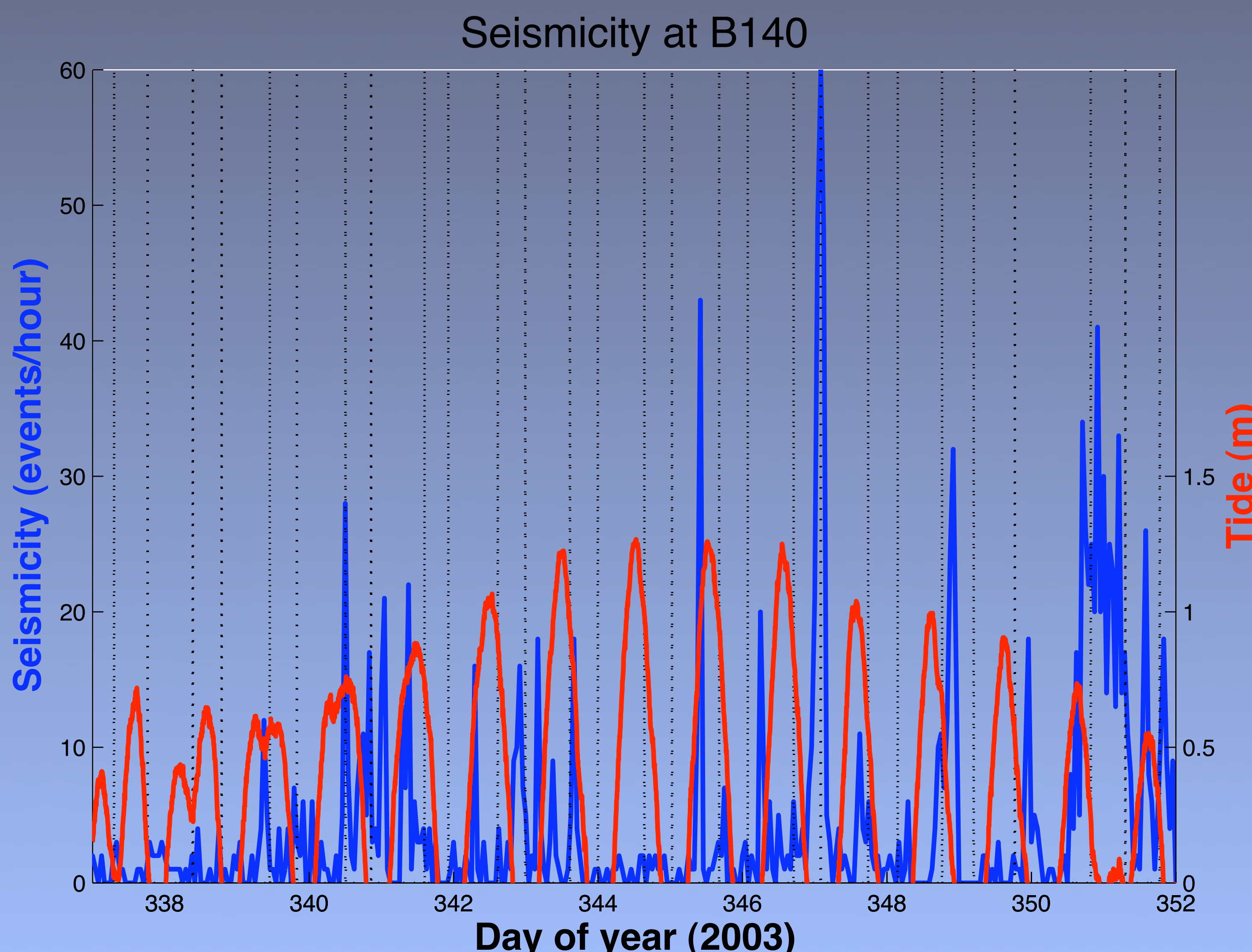
Observations (2)

- At B10 (near the grounding line of ice stream B)
  - Seismicity peaks occur during the neap to spring tide cycle
  - Seismicity is suppressed during the spring to neap tide cycle.

B90 - 90 km up from G. L.



B140 - 140 km up from G. L.



Observations (3)

- Upstream from the grounding line, the seismicity is “peaked”, generally once per day, but sometimes more
  - BUT, not tied to the slip event times...
    - Not inconsistent with a model of a propagating wave from the grounding line
    - Difficult to quantify propagation speed because of difficulty correlating from station to station

Hypotheses

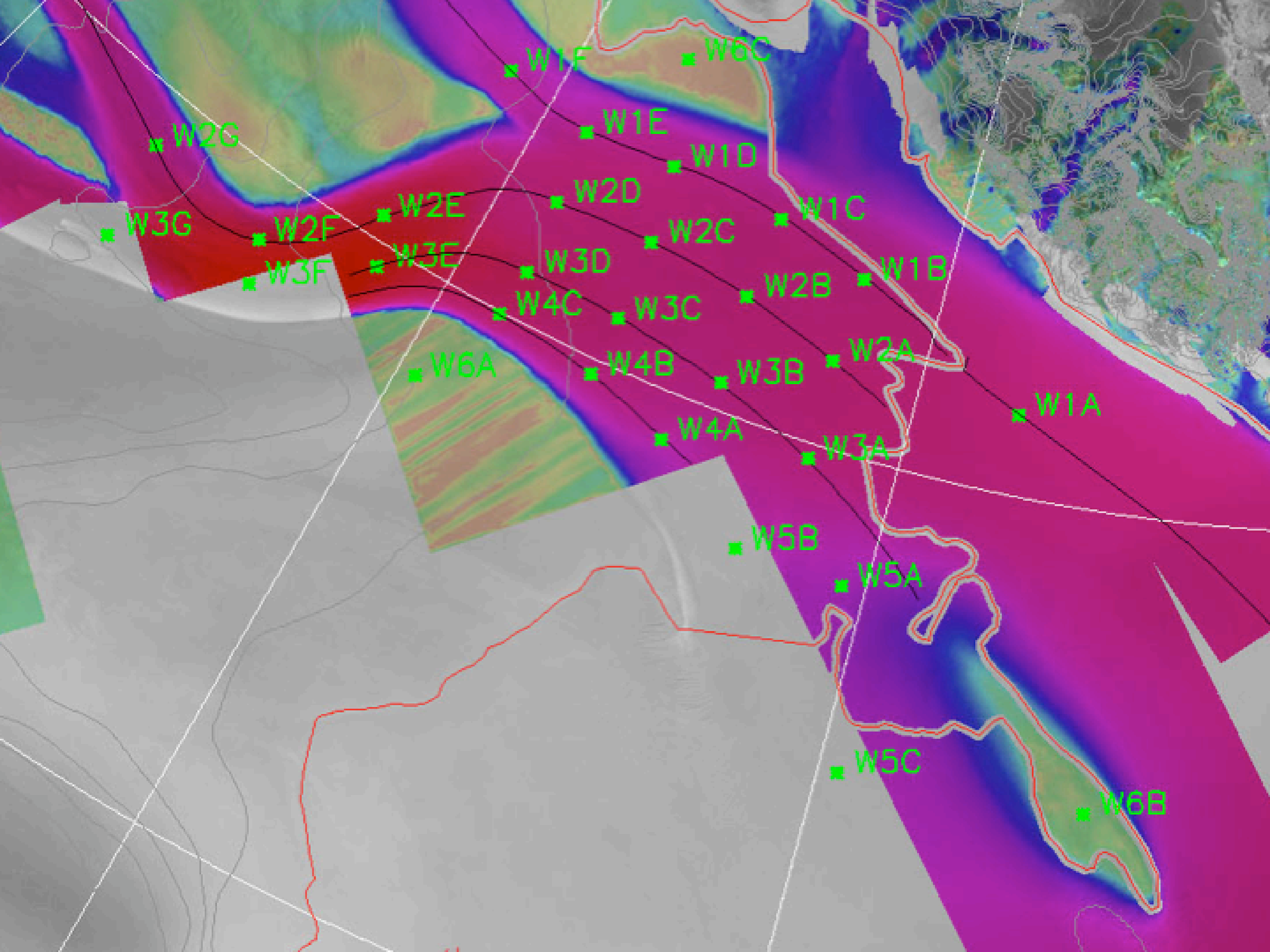
- The bed at the grounding line is very sensitive to the ocean tide.
  - The bed at the grounding line is weak. The strain from the slip accumulates until the bed fails.
- There is a "hysteresis" associated with the highest high tide (spring tide).
  - The bed is weakened further so that the slip of the ice stream does not cause seismic slip/failure
  - Or, water infiltrates up from the grounding line, allowing asiesmics sliding.

Hypotheses

- The bed is more heterogeneous upstream of the grounding line
  - More seismicity from various hypocenters
  - Continuous, low-level seismicity

Conclusions

- Basal seismicity is associated with slip at the grounding line (though not all slip is associated with seismicity)
- The tide can profoundly affect the properties of the bed.
  - Continued work will help distinguish between different hypotheses.



W6C
W1F
W1E
W2G
W1D
W2D
W1C
W2E
W3G
W2F
W2C
W3E
W3D
W1B
W3F
W2B
W4C
W3C
W2A
W6A
W4B
W3B
W1A
W4A
W3A
W5B
W5A
W5C
W6B