Validation activities for the Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) Mission

Tom Neumann
Kelly Brunt
Lori Magruder
Nathan Kurtz

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Calibration and validation of Earth satellite measurements
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ICESat-2 surface measurement validation

ICESat-2 Project Science Office has a data-product validation plan

- Includes using ground-based, airborne, and satellite datasets
- Addresses validation of mission requirements (specifically land ice and sea ice)

- Height accuracy/precision requirements:
  - variable, based on geophysical surface
  - most stringent: ice-sheet elevation change rates to an accuracy ***0.4 cm per year***

- Across-track and along-track offsets:
  - geolocation knowledge requirement is ***6.5 m***

ICESat-2 surface measurement validation activities

Project Science Office and Science Team validation activities, various sites, various goals:

- 88°S Antarctic Traverse (3 kinematic GPS surveys); ***z validation***
- IceBridge airborne lidar surveys; ***x, y, and z validation***
- Summit Traverse 72°N (kinematic GPS, monthly since 2006!); ***z validation (dz/dt)***
- White Sands Missile Range 32°N and

  88°S corner cube retroreflector (CCR) analysis; ***x, y, and z validation***
- White Sands Missile Range 32°N airborne lidar survey; ***x, y, and z validation***

Examples: 88°S Antarctic Traverse (3 kinematic GPS surveys)

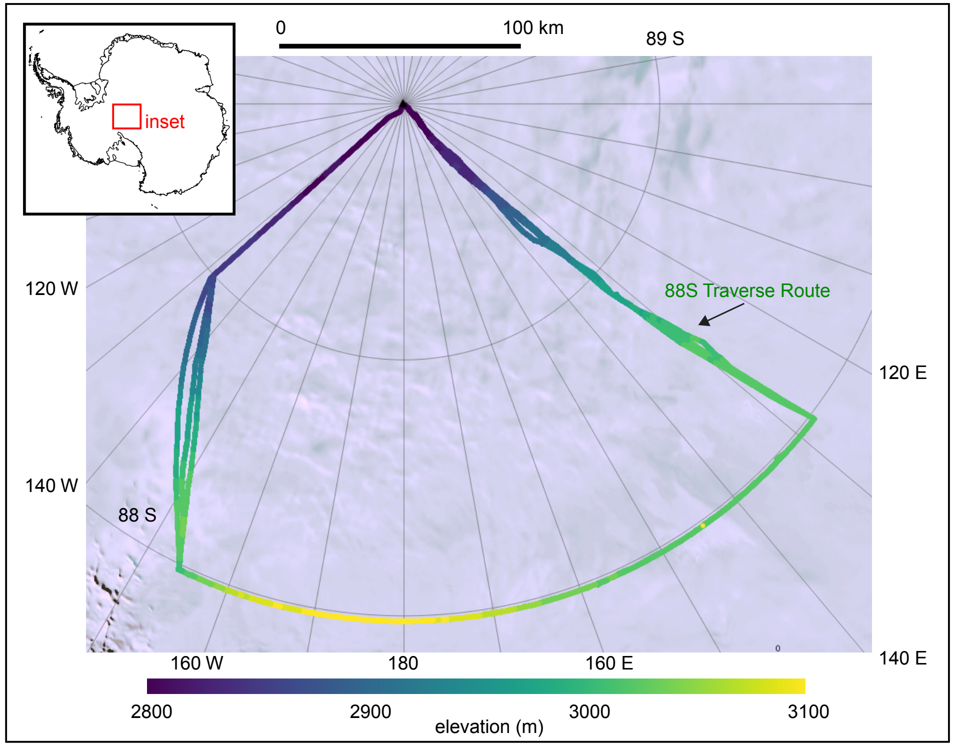
Assessment of ICESat-2 Ice Sheet Surface Heights, Based on Comparisons Over the Interior of the Antarctic Ice Sheet

K. M. Brunt[1,2], T. A. Neumann[2], and B. E. Smith[3]

(2019) GRL, *46*(22), doi:10.1029/2019GL084886

Results from Tables 1 and 2:

ATLAS spot	ATL03 bias ± precision (cm; with buffer)	ATL06 bias ± precision (cm)
1	−0.7 ± 12.7	−2.8 ± 8.9 ($N = 661$)
2	+0.8 ± 9.6	−1.5 ± 8.8 ($N = 645$)
3	+3.4 ± 9.3	+1.7 ± 7.7 ($N = 1{,}018$)
4	+2.6 ± 8.9	+0.6 ± 7.9 ($N = 1{,}009$)
5	+3.9 ± 11.0	+2.3 ± 7.6 ($N = 863$)
6	+4.6 ± 11.0	+2.7 ± 8.1 ($N = 805$)



Traverse map

ATL03 heights (on low slope regions) are "currently accurate to better than 5 cm with better than 13 cm of surface measurement precision" (Brunt et al., 2019)

ATL06: heights (on low slope regions) are "currently accurate to better than 3 cm with better than 9 cm of surface measurement precision" (Brunt et al., 2019)

Examples: IceBridge airborne lidar surveys

Assessment of altimetry using ground-based GPS data from the 88S Traverse, Antarctica, in support of ICESat-2

Kelly M. Brunt[1,2], Thomas A. Neumann[2], and Christopher F. Larsen[3]

(2019) Cryosphere, 13(2), doi:10.5194/tc-13-579-2019

Results from Table 1:

Lidar survey	PPP bias ± precision: relative to GPS A (cm) relative to GPS B (cm)
ATM 26 October 2014	2.8 ± 14.0 3.6 ± 14.1
UAF lidar 30 November 2017	0.1 ± 9.7 0.2 ± 9.5
UAF lidar 3 December 2017	−9.5 ± 9.8 −8.0 ± 9.7

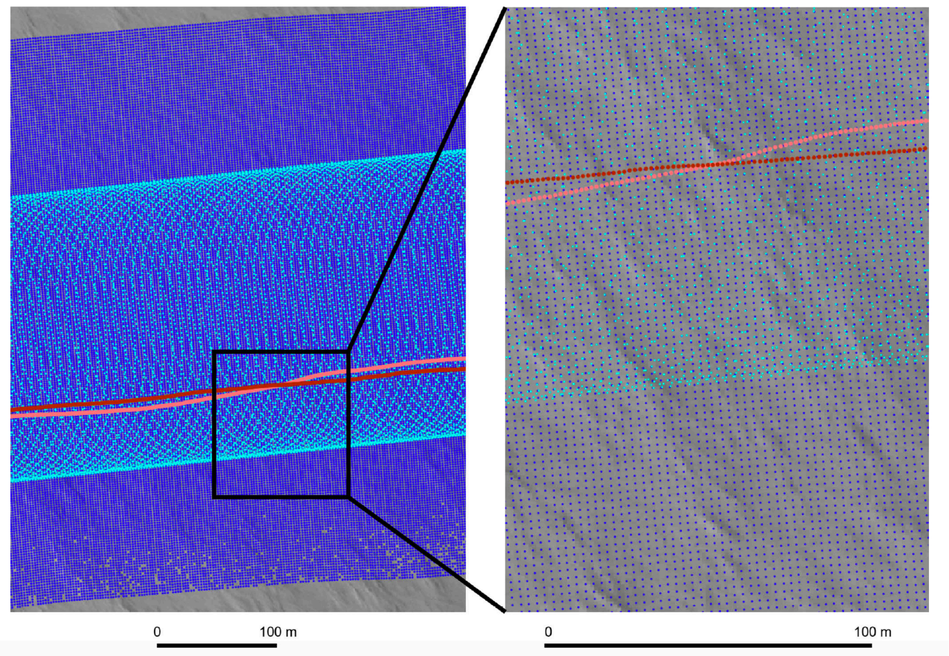


Figure 3. Footprint spacing for OIB lidars (blues), and the 88S Traverse GPS data (reds). WorldView-2, DigitalGlobe, Inc.

OIB lidar (on low slope regions) biases "range from -9.5 to 3.6 cm with surface measurement precisions better than 14.1 cm" (Brunt et al., 2019)

Examples: Summit Traverse 72ºN (kinematic GPS, monthly since 2006!)

Assessment of NASA airborne laser altimetry data using ground-based GPS data near Summit Station, Greenland

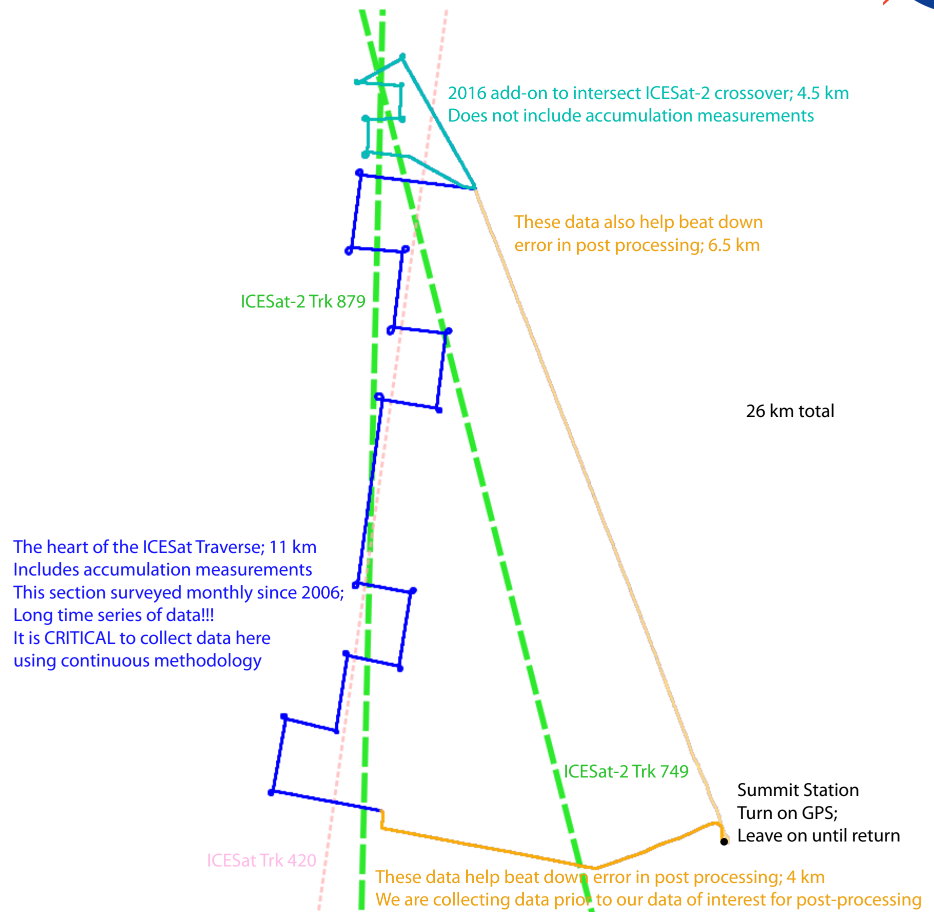
Kelly M. Brunt[1,2], Robert L. Hawley[3], Eric R. Lutz[3], Michael Studinger[2], John G. Sonntag[4,5], Michelle A. Hofton[6], Lauren C. Andrews[7,2], and Thomas A. Neumann[2]

(2017) Cryosphere, 11(2), doi:10.5194/tc-11-681-2017

*** Only 9 successful GPS comparisons of ICESat-2 overpasses*

*** Thus, current published results are limited to assessments of OIB lidars*

Figure 2. GPS antenna, sled, and snowmobile configuration.



OIB lidar (on low slope regions) biases "are less than 12 cm, while assessments of surface measurement precision are 9 cm or better" (Brunt et al., 2017)

Examples: White Sands Missile Range 32ºN and 88ºS CCR analysis and WSMR airborne lidar survey

ICESat-2 horizontal geolocation accuracy validation using ground-based corner cube retro-reflectors

Lori A. Magruder, Kelly M. Brunt and Michael Alonzo

(in review) IEEE Transactions on Geoscience and Remote Sensing

CCR at 88S

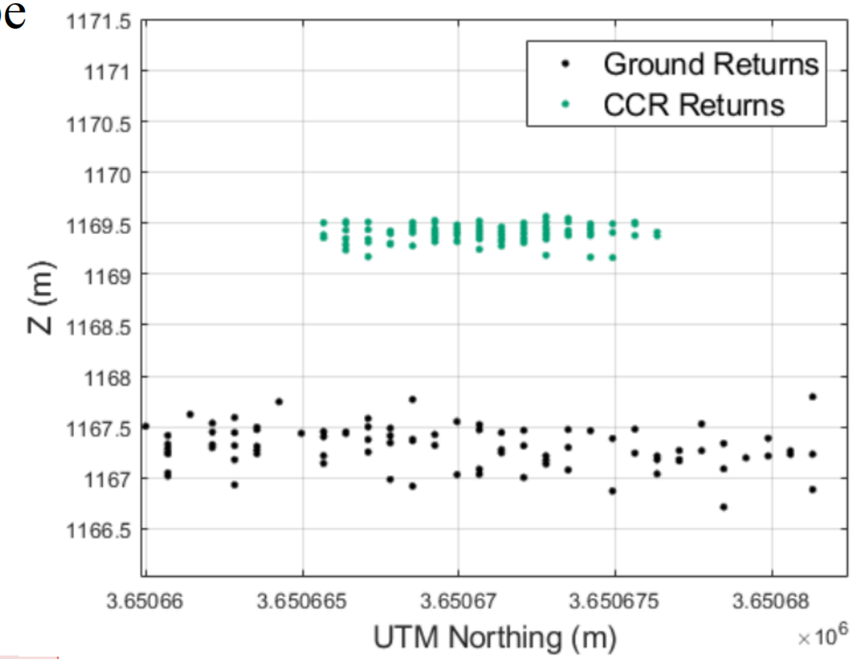


Figure 6. Strong beam CCR signature.

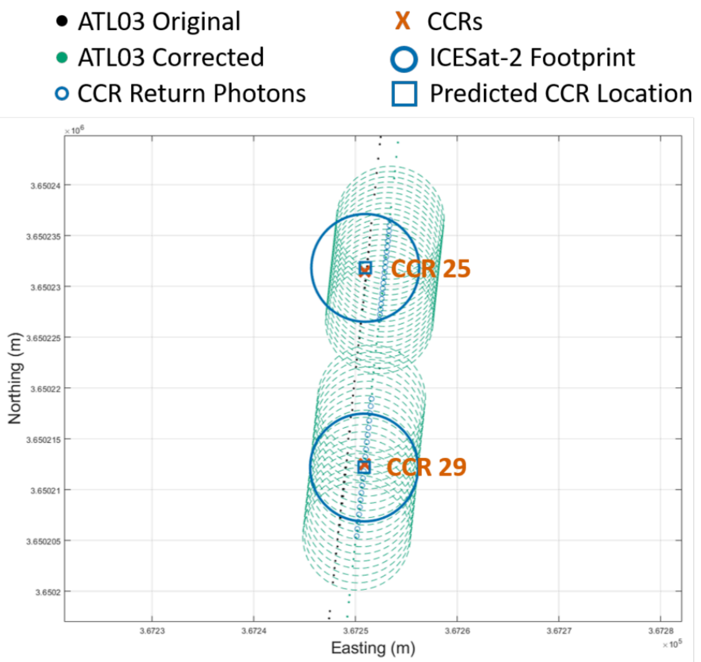


Figure 18. CCR geolocation accuracy and signal chord lengths.

"Two successful CCR signature collections indicate a geolocation accuracy range of 2-5 m and an average beam diameter recovery of ~11 m" (Magruder et al., in review)

Goal: Determine ice-sheet elevation change rates to an accuracy 0.4 cm per year

Science REPORTS

Cite as: B. Smith *et al.*, *Science* 10.1126/science.aaz5845 (2020).

Pervasive ice sheet mass loss reflects competing ocean and atmosphere processes

Ben Smith[1*], Helen A. Fricker[2], Alex S. Gardner[3], Brooke Medley[4], Johan Nilsson[3], Fernando S. Paolo[3], Nicholas Holschuh[5,6], Susheel Adusumilli[2], Kelly Brunt[7], Bea Csatho[8], Kaitlin Harbeck[9], Thorsten Markus[4], Thomas Neumann[4], Matthew R. Siegfried[10], H. Jay Zwally[4,7]

*** Highly accurate, highly precise surface elevation measurements will enable ICESat-2 to meet Level-1 science requirement of determining ice-sheet elevation change rates to an accuracy 0.4 cm per year.*

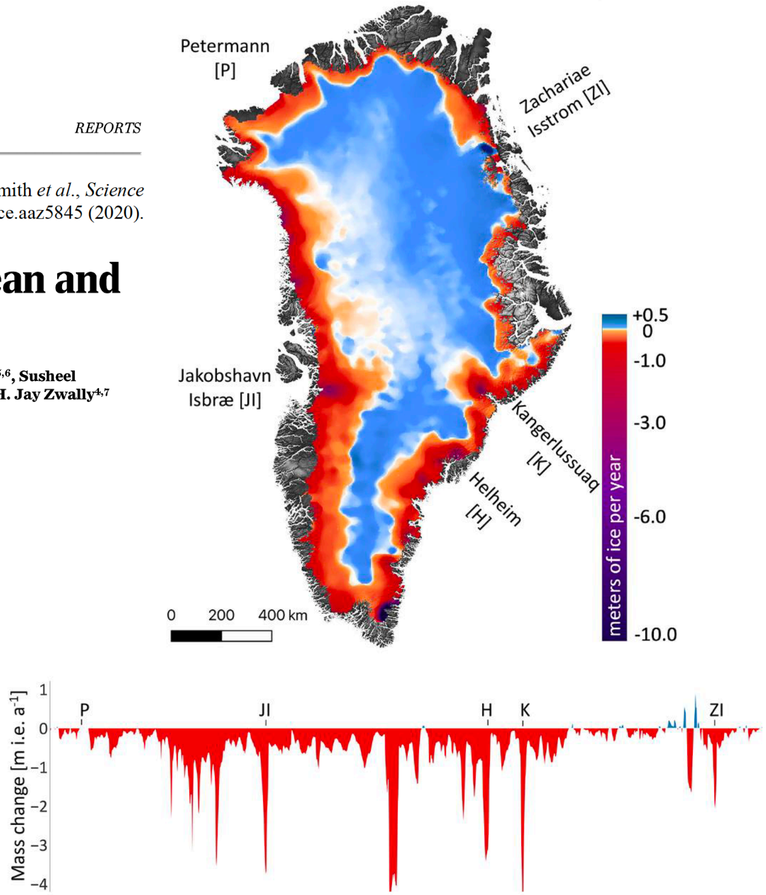


Figure 2. Mass loss Greenland (2003– 2019)

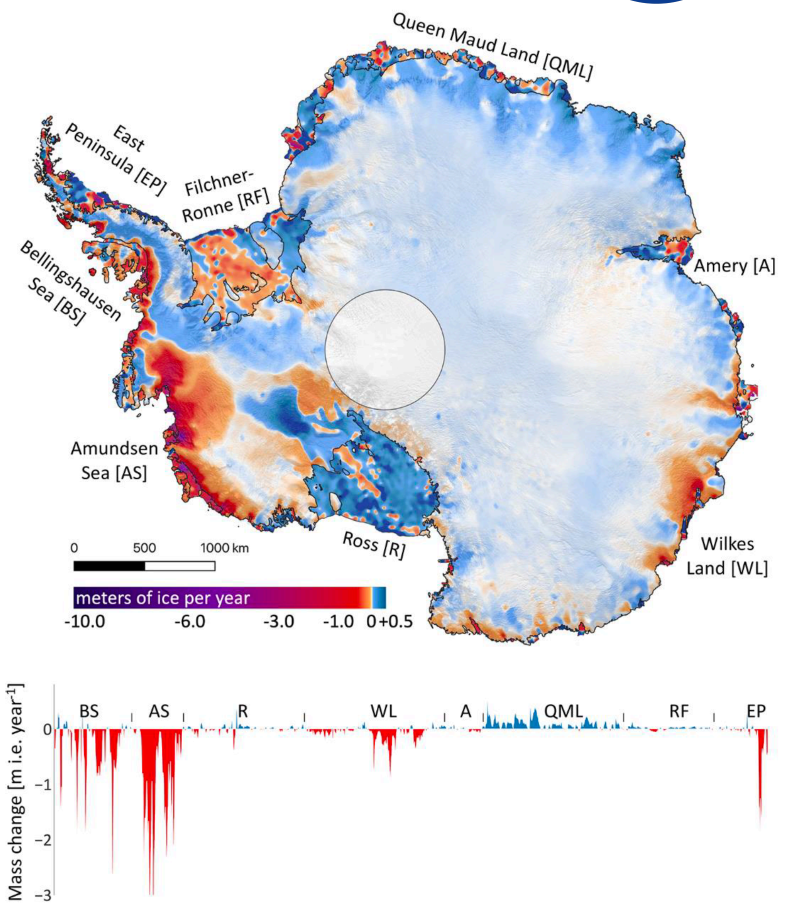
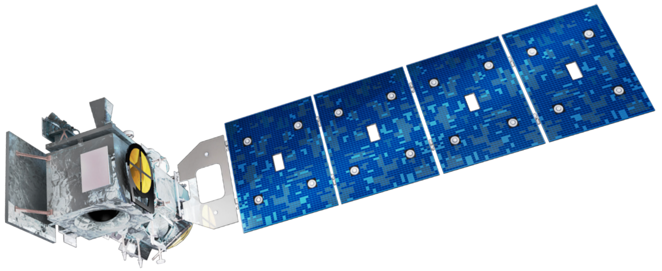


Figure 3. Mass loss Antarctica (2003– 2019)

For the ICESat-2 center, strong beam, "the bias was +1.7 cm with a 7.7 cm 1-sigma standard deviation" (Smith et al., 2020)

ICESat-2 surface measurement validation



Project Science Office and Science Team validation activities:

- Most results here represent large spatial scales; many orbits; spanning latitude; long time scale
- However, we acknowledge that they are only assessments associated with a single site.
- ***ATL03: heights (on low slope regions) are "currently accurate to better than 5 cm with better than 13 cm of surface measurement precision" (Brunt et al., 2019)***
- ***ATL06: heights (on low slope regions) are "currently accurate to better than 3 cm with better than 9 cm of surface measurement precision" (Brunt et al., 2019)***
- ***ICESat-2: ""Two successful CCR signature collections indicate a geolocation accuracy range of 2-5 m and an average beam diameter recovery of ~11 m" (Magruder et al., in review)***

*Suggested manuscript language: "ICESat-2 height accuracy is currently better than 10 cm;
horizontal location accuracy is currently better than 10 m;
ICESat-2 footprint diameter is <17 m"*