

# ICESat-2

*Global STEM Education:  
What's Next  
@ Harvard Graduate School of  
Education,  
Cambridge MA  
May 24, 2019*



**Frank Martin**

Standing Review Board Chair for ICESat-2

*Details provided by Tom Neumann, Project Scientist and the entire ICESat-2 Team*

# The Polar Regions, Ice sheets?

- Formed by snow accumulation
- Up to 4000m thick
- Move slowly (up to km/year)
- Either melt or make icebergs
- Greenland, Antarctica





# The Polar Regions, Sea Ice?

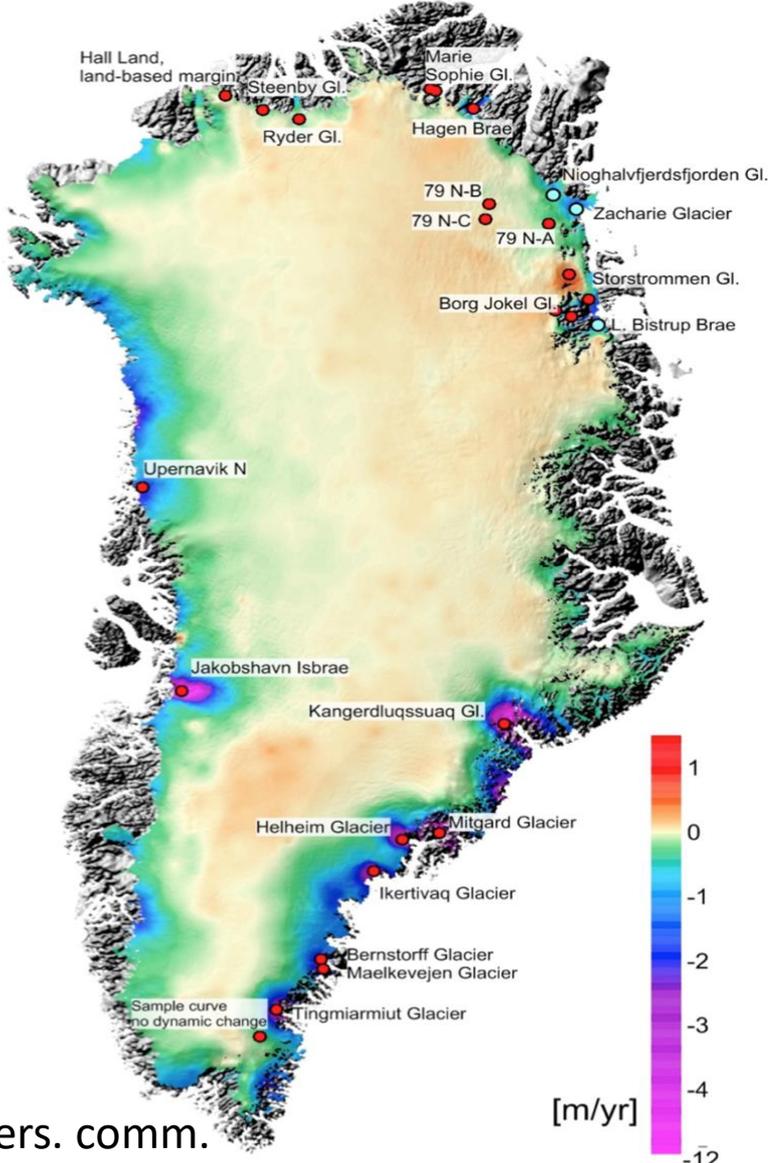


- Formed by freezing ocean water
- Up to 20m thick
- Move quickly (km/day)
- Melt seasonally
- Arctic and Antarctic seas





# Ice Sheet Changes: Greenland



Ice mass loss is concentrated near the coast in both Greenland and Antarctica →

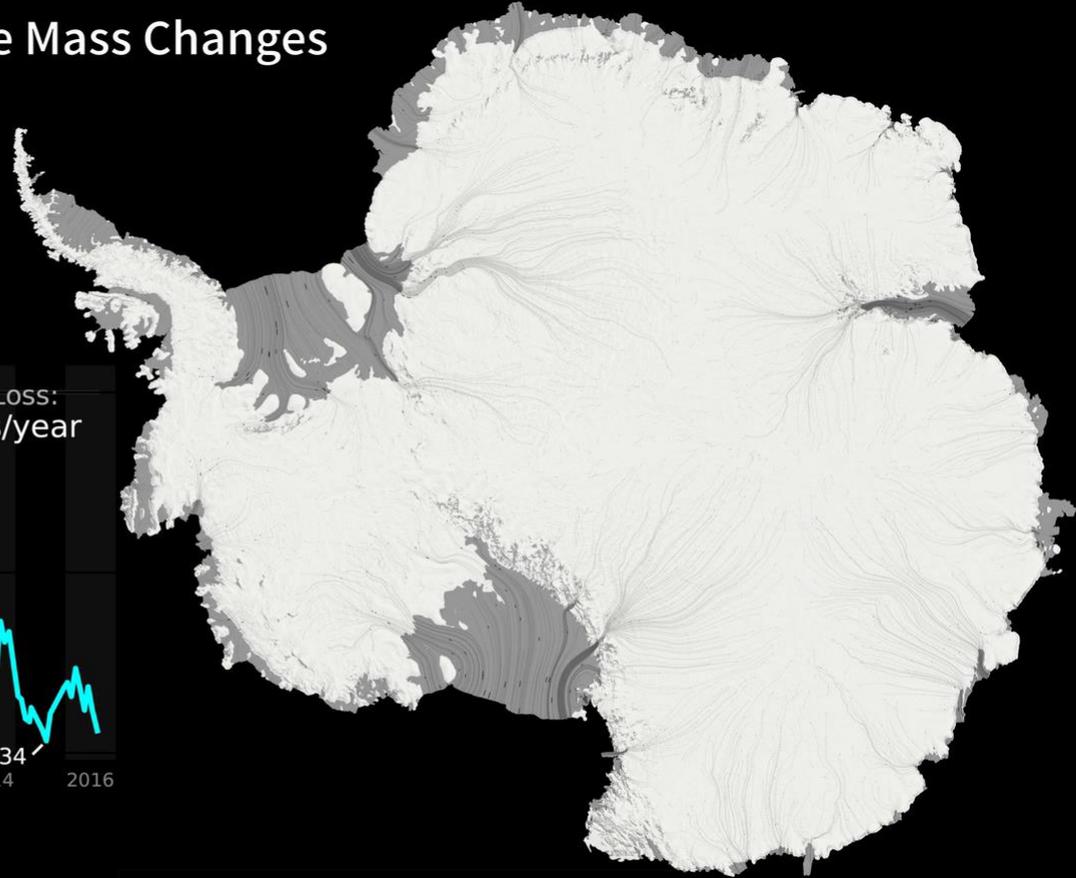
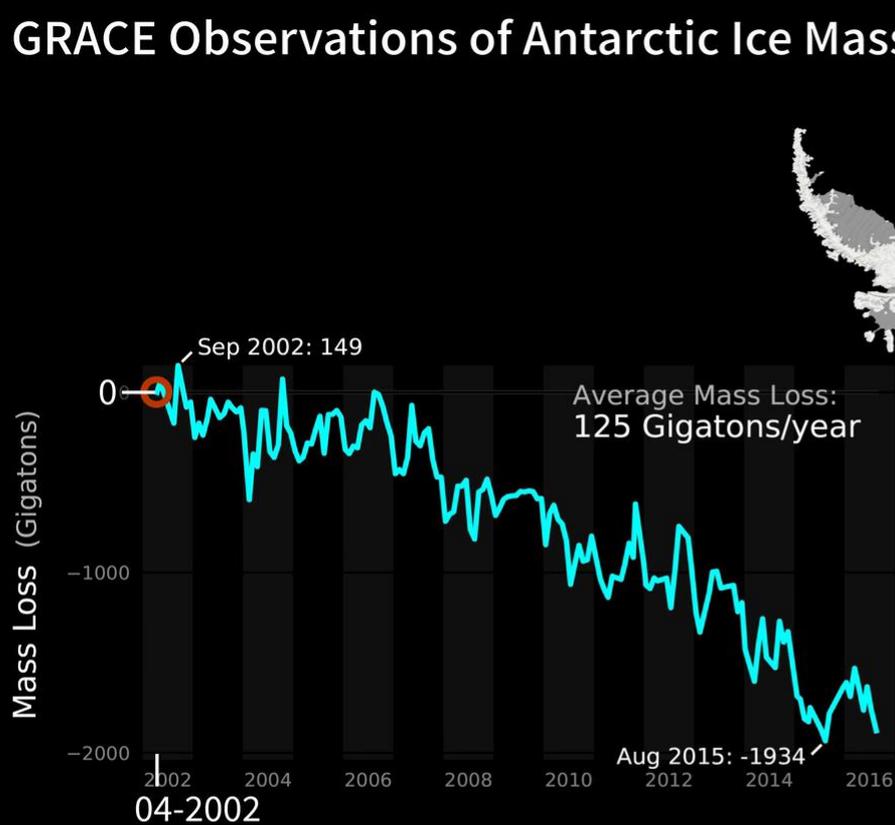
Csatho, pers. comm.



# Ice Sheet Changes: Antarctic



## GRACE Observations of Antarctic Ice Mass Changes



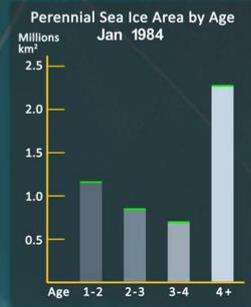


# Sea Ice Changes: Arctic



Jan 1984

Sea Ice Age





# Sea Ice Changes: Arctic

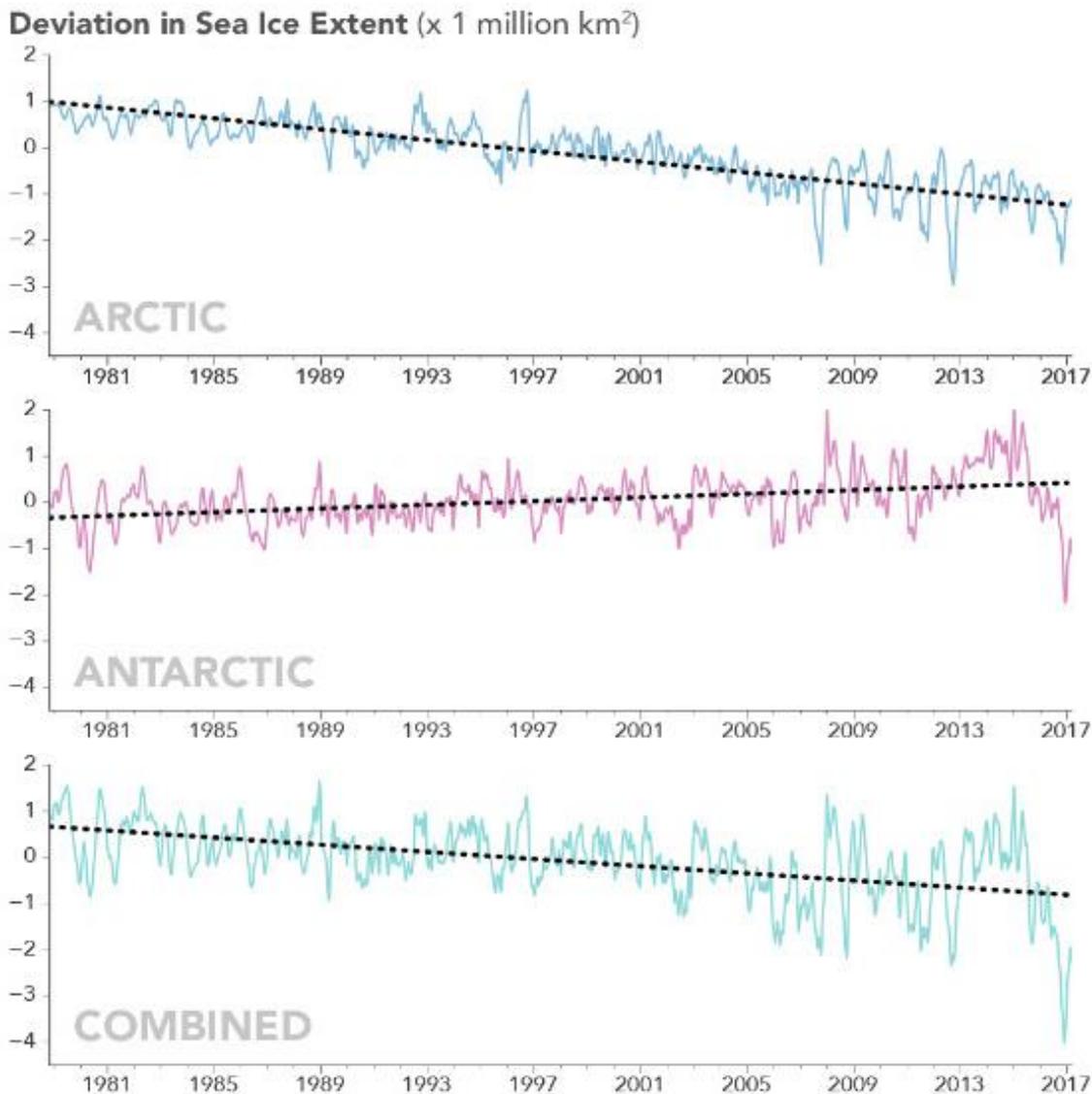




# Sea Ice Changes: Antarctica

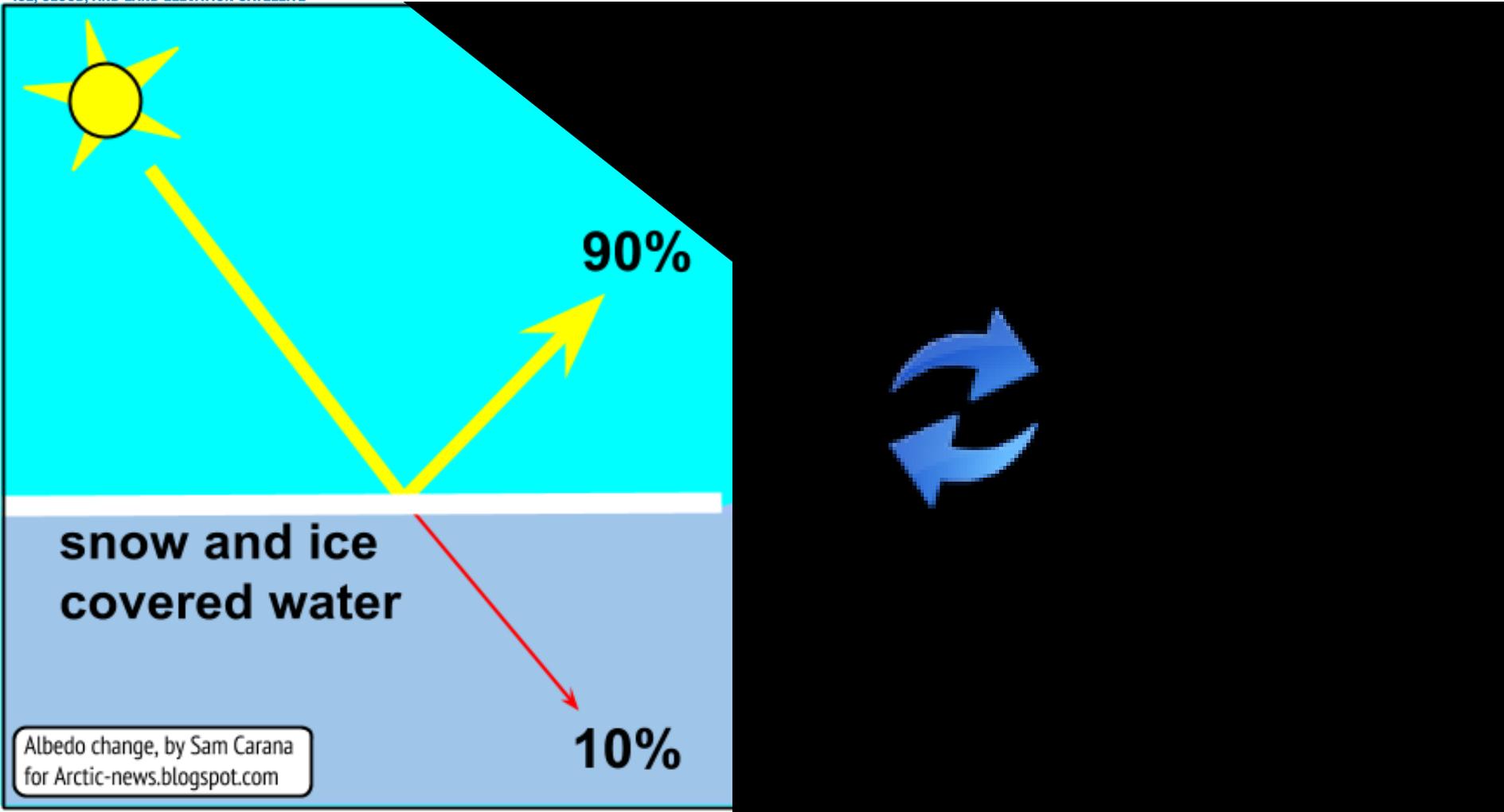
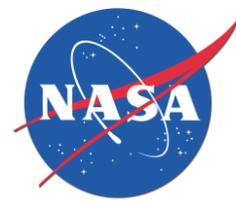


We can readily measure sea ice *extent*, but not thickness





# Self-reinforcing Feedback Loop



Impacts polar-equatorial temperature gradients →  
jet-streams and ocean circulators.



# Two New Missions!



## Gravity Recovery and Climate Experiment

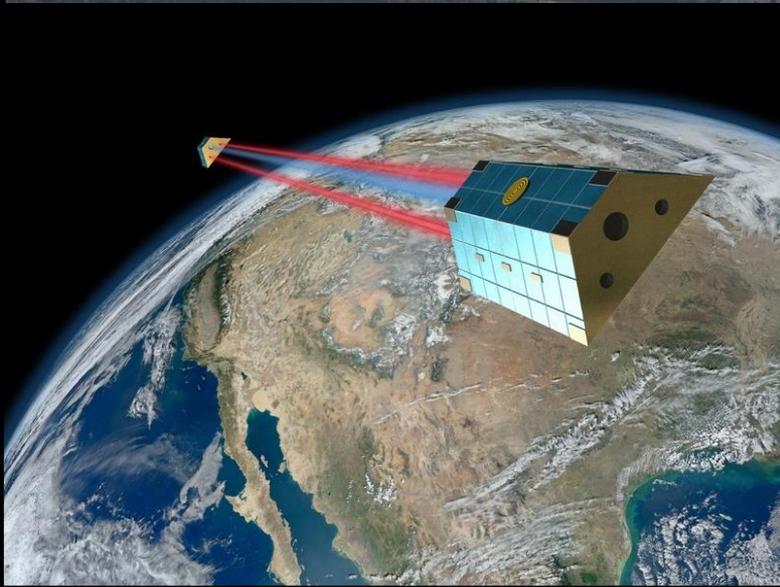
*GRACE-Follow On*

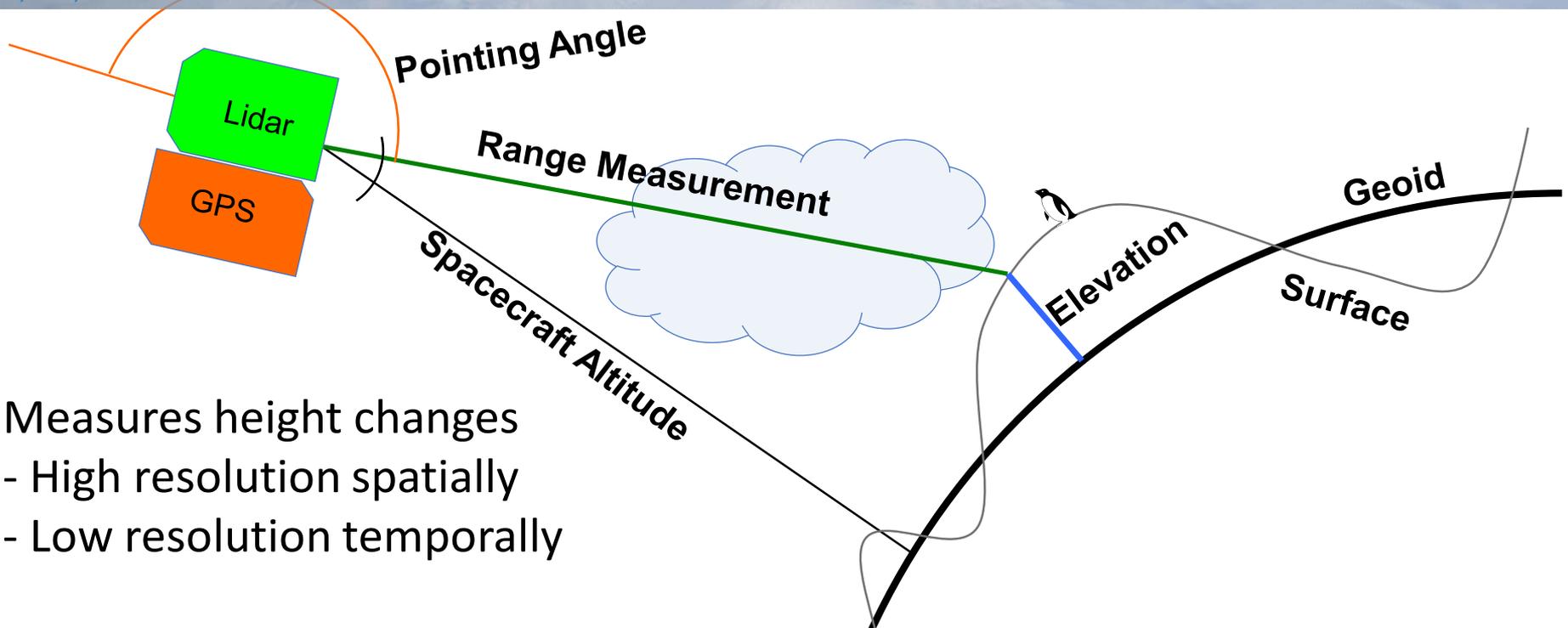
*22 May 2018*

*NASA JPL*



*ICESat-2*  
*15 Sept 2018*





Measures height changes

- High resolution spatially
- Low resolution temporally

We want to measure **elevation**

Lidar measures **range (time of flight)** and **absolute pointing angle**

**GPS** measures position in orbit

Ground processing puts the pieces together



# ICESat-2 Measurement Concept



ICESat-2 uses *micro-pulse multi-beam photon counting* approach to making height measurements.

## Provides:

Dense cross-track sampling to resolve surface slope on an orbit basis.

High repetition rate (**10 kHz**) generates dense along-track sampling (**~70 cm**).

Different beam energies to provide necessary dynamic range (bright / dark surfaces).

## Advantages:

Improved elevation estimates over high slope areas and very rough (e.g. crevassed) areas. Improved lead detection for sea ice freeboard.

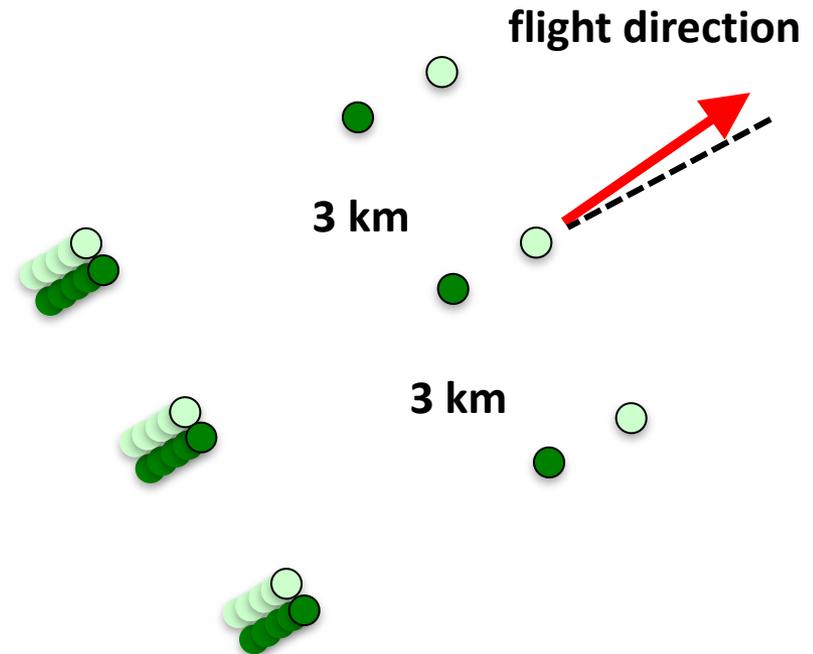
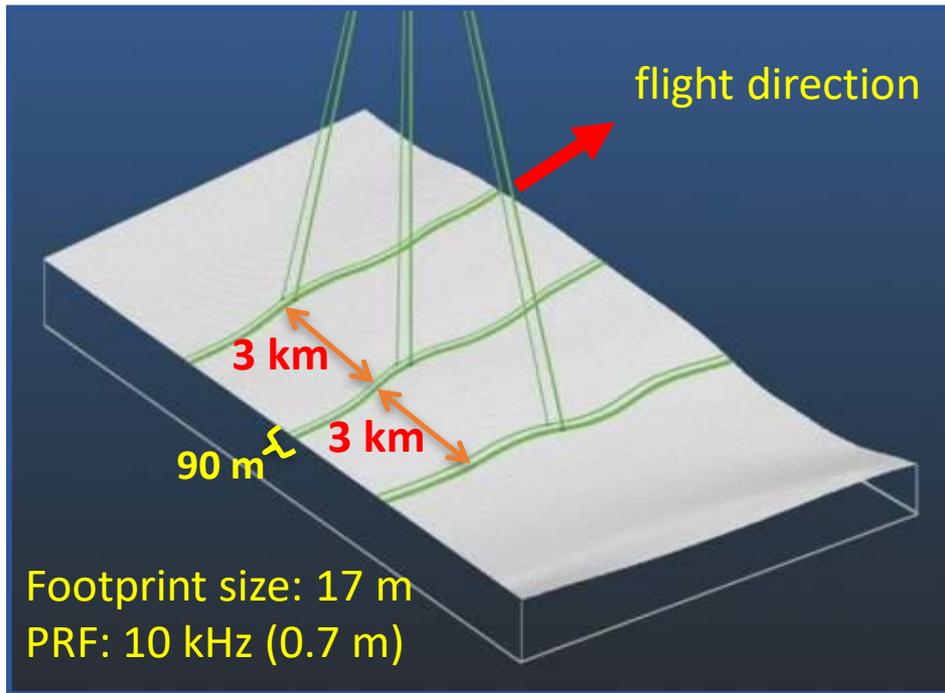




# ICESat-2 Measurement Concept



Single laser pulse at 532nm, split into 6 beams. Single-photon sensitive detection.



3 km spacing between pairs provides spatial coverage

90 m pair spacing for **slope determination** ( $2^\circ$  yaw)

**High-energy beams (4x)** for better performance over low-reflectivity targets.



# ICESat-2!



## Orbit

310 miles altitude,  
92-degree inclination,  
91-day repeat

## Speed

4.3 miles per second (15,480 mph)

## Power

4 Solar panels  
average of 1320 Watts

## Data

Onboard recorder stores 580 gigabits/day,  
X-band downlink sends 220Mbits a second.



**ATLAS (Laser Instrument)** 550kg ,  
Spacecraft Dry Mass 906 kg,  
Propellant 134 kg (7 years)



# ICESat-2!



7:00 PM PST



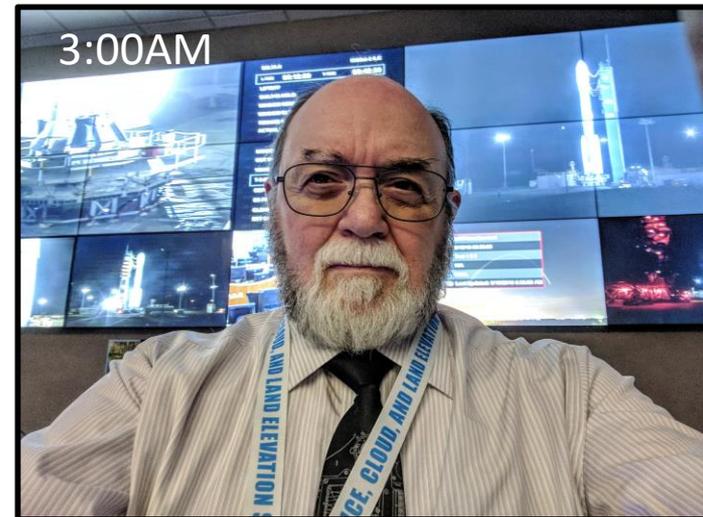
11:30 PM PST



Team Members spend years, sometimes decades devoting careers and lives to space missions.

**Launch day is a personal and deeply human experience.**

3:00AM



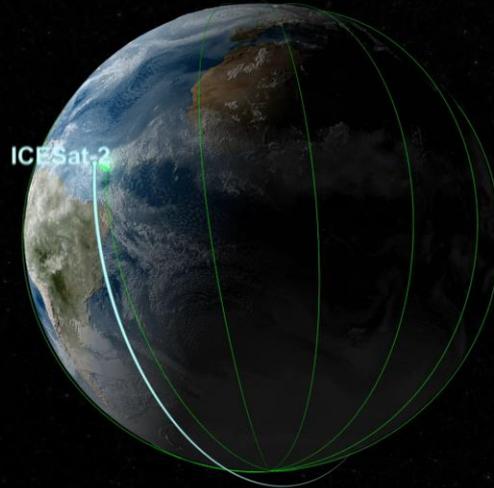


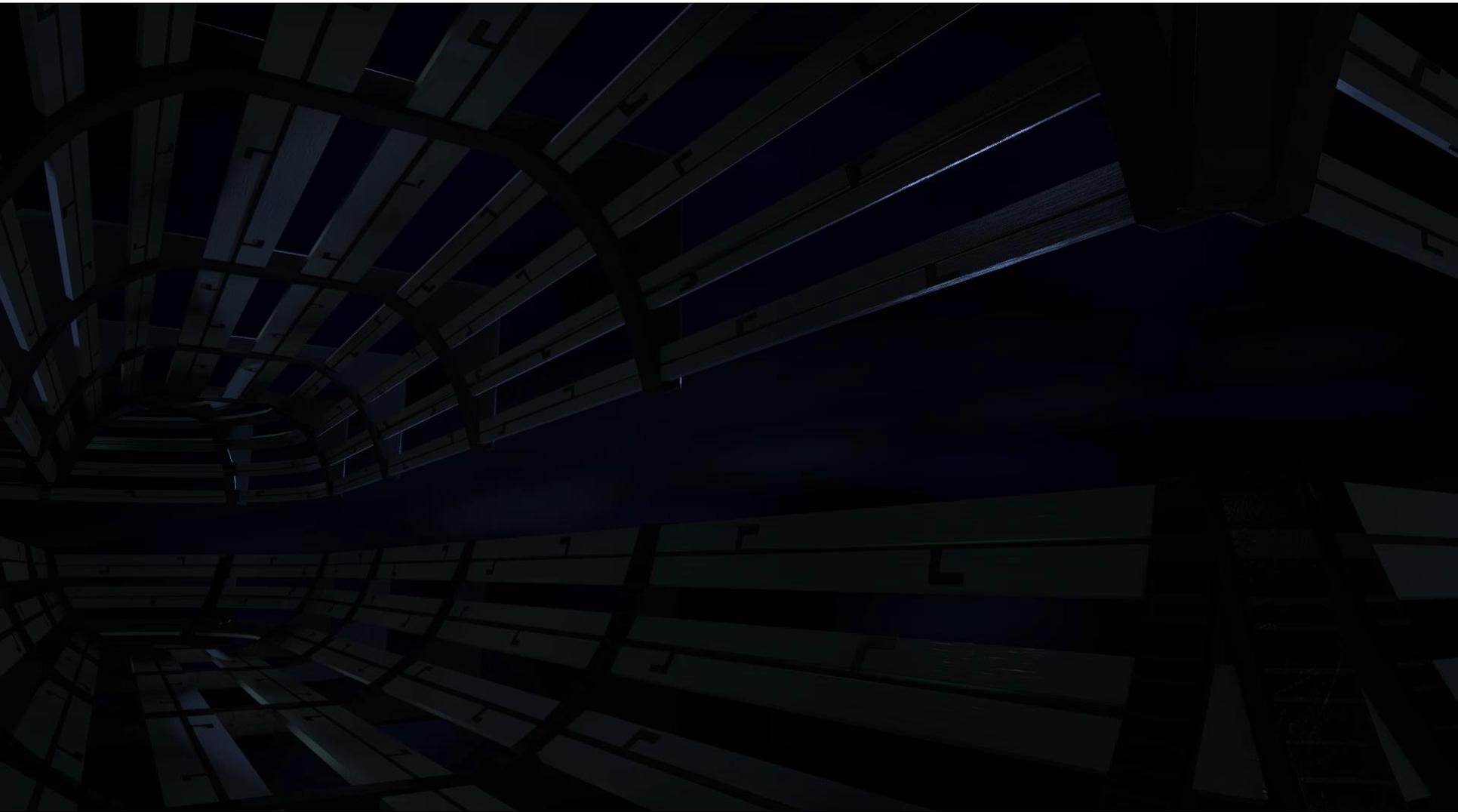
# Launch and Separation



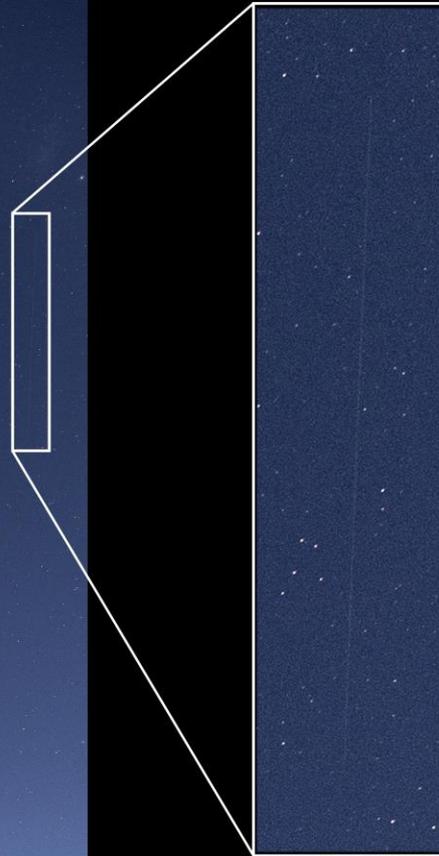
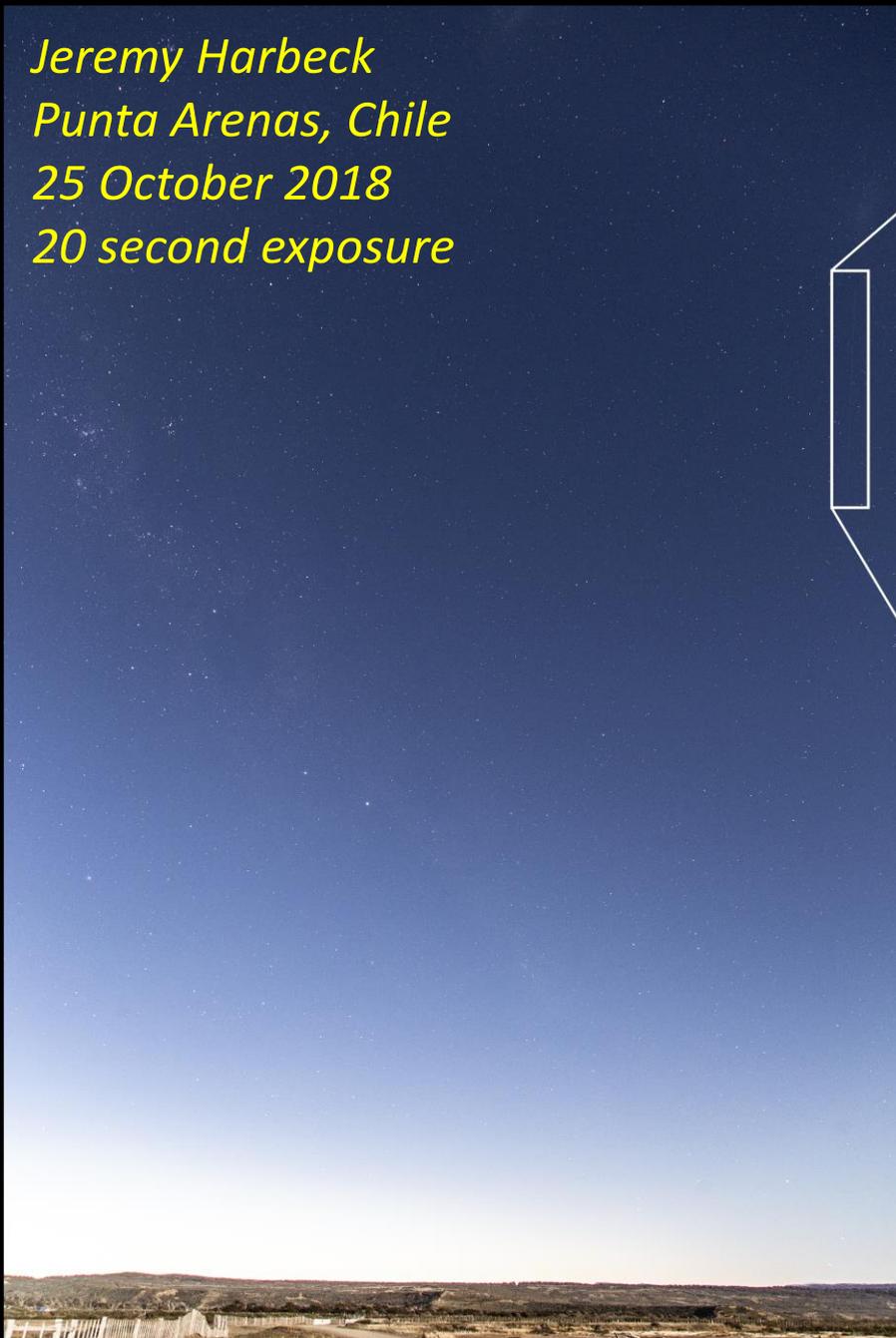


# Orbit Coverage



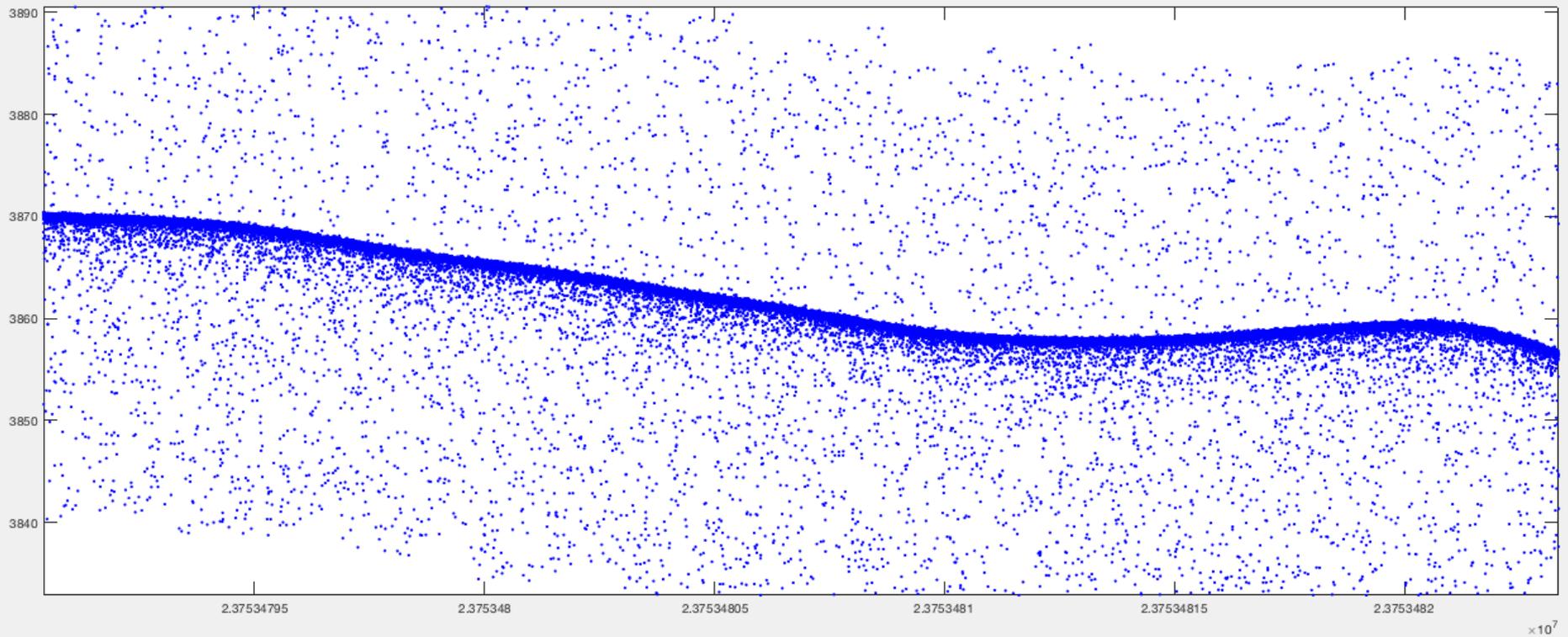


*Jeremy Harbeck  
Punta Arenas, Chile  
25 October 2018  
20 second exposure*





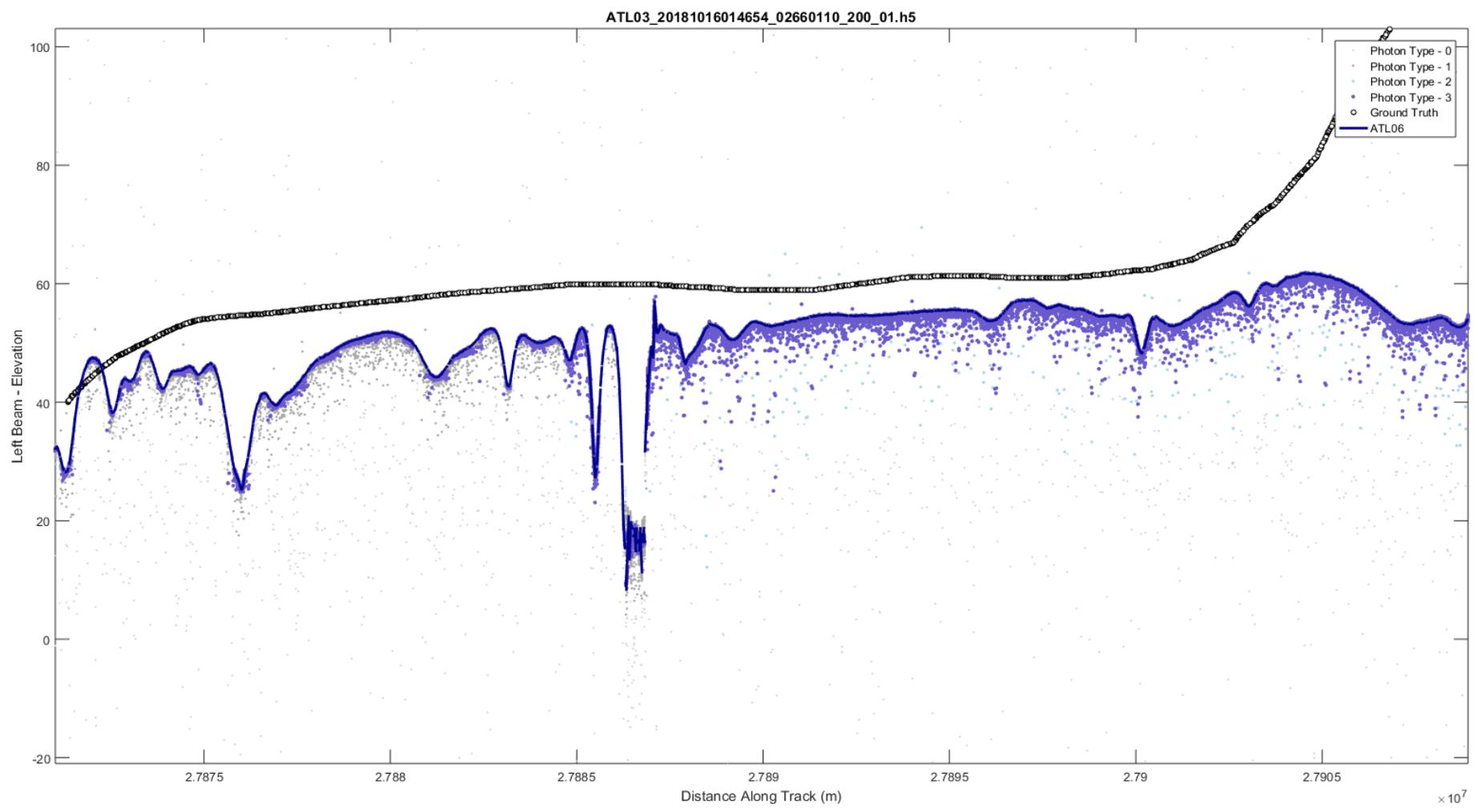
# What DOES the data look like?



$\times 10^7$

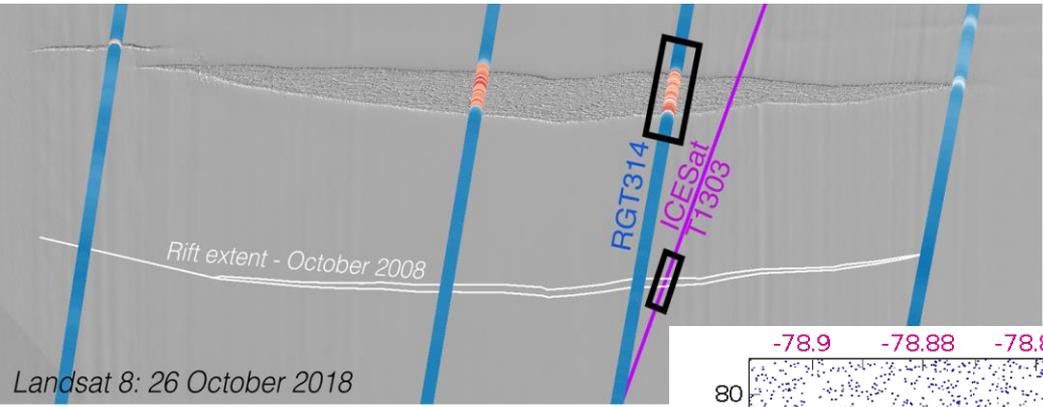


# What DOES the data look like?

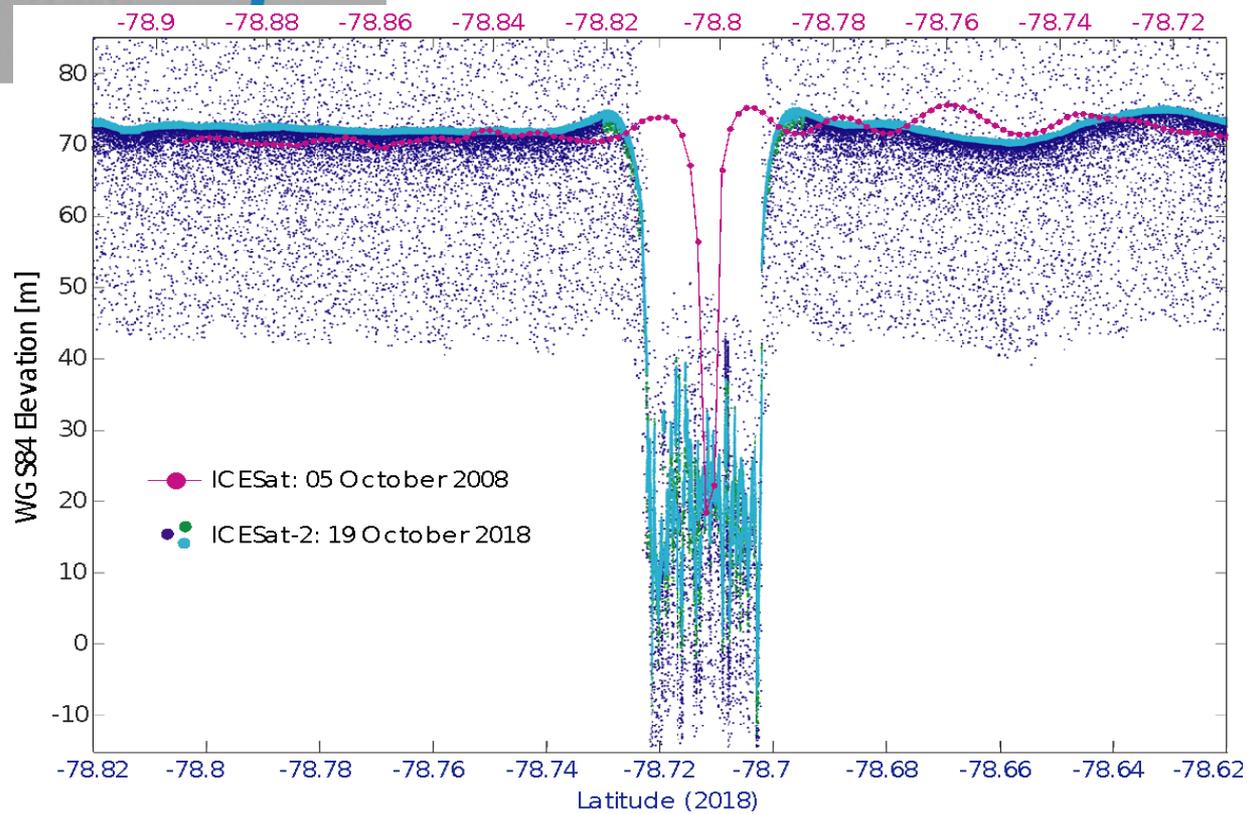




# What DOES the data look like?



## Filchner Ice Shelf, West Antarctica





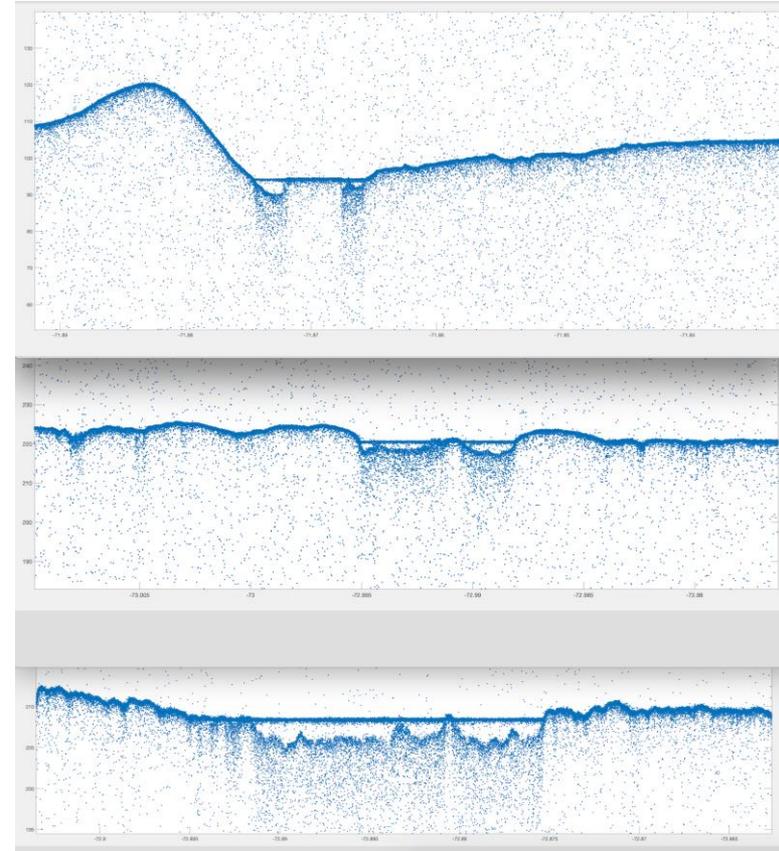
# What DOES the data look like?



Amery Ice Shelf undergoes extensive surface melt each summer, which flows as melt streams

ICESat-2 penetrates the water and allows us to estimate the depth of melt ponds

Combined with satellite imagery, this will provide meltwater volume estimates

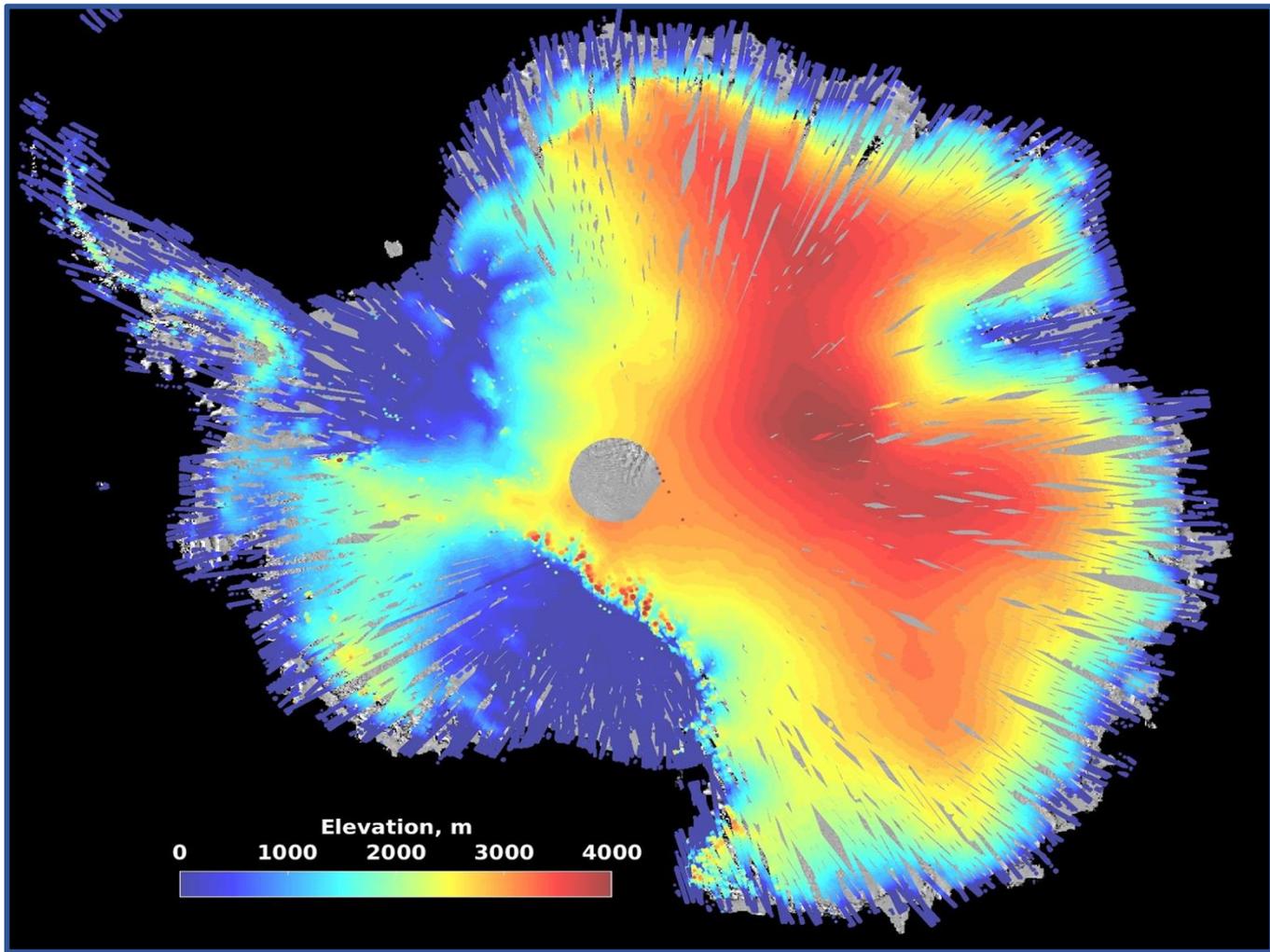




# What DOES the data look like?



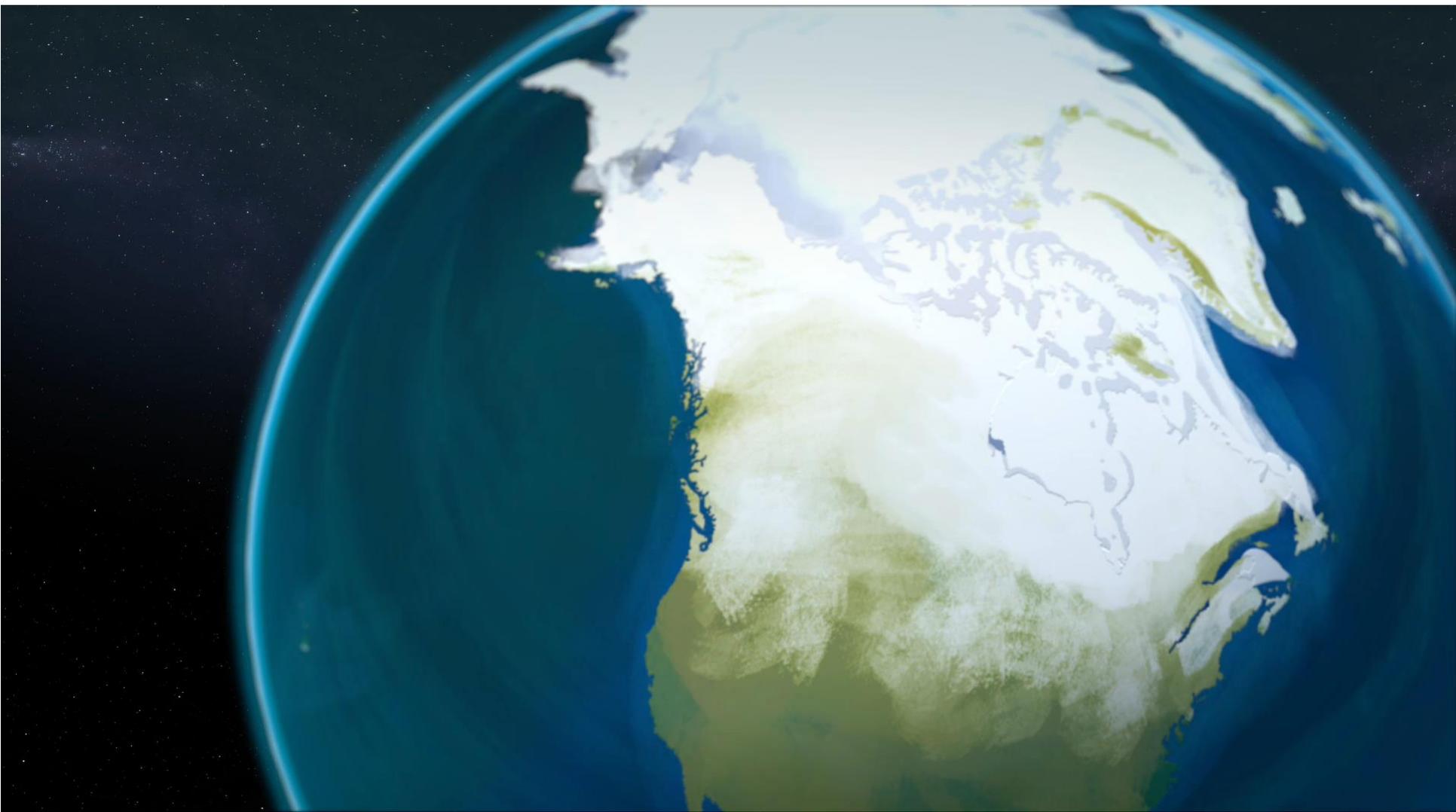
First three weeks of observations over Antarctica



Ben Smith, University of Washington

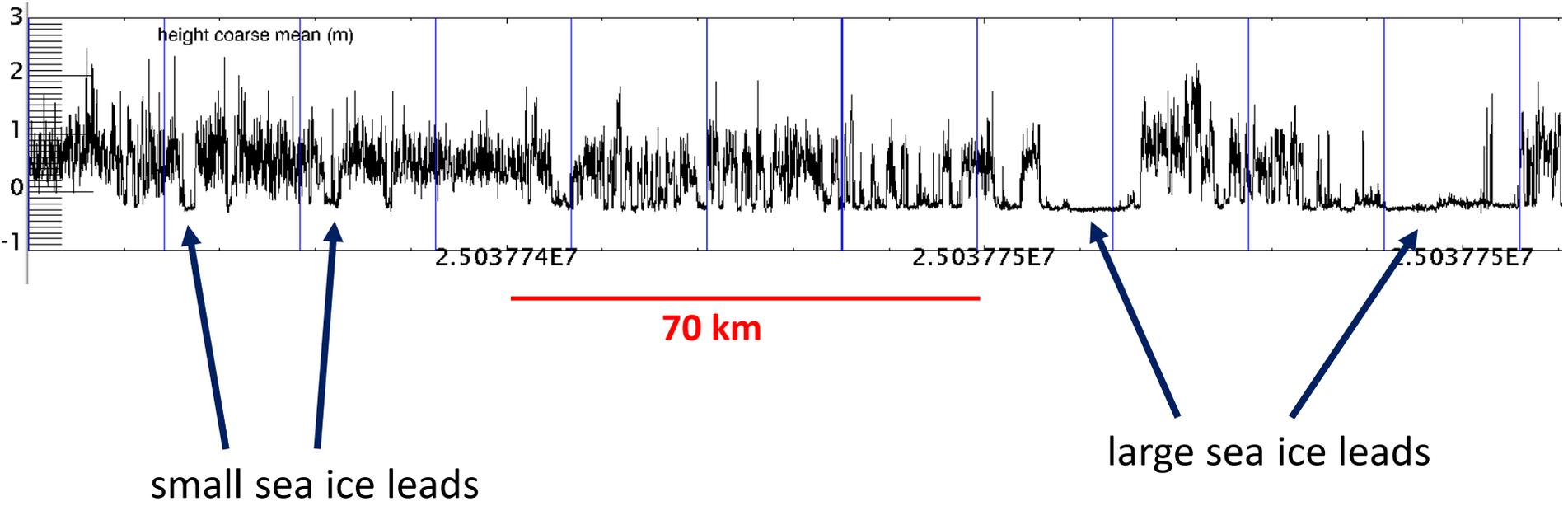


# Sea Ice Objectives (they're a little different)





# What DOES the data look like?



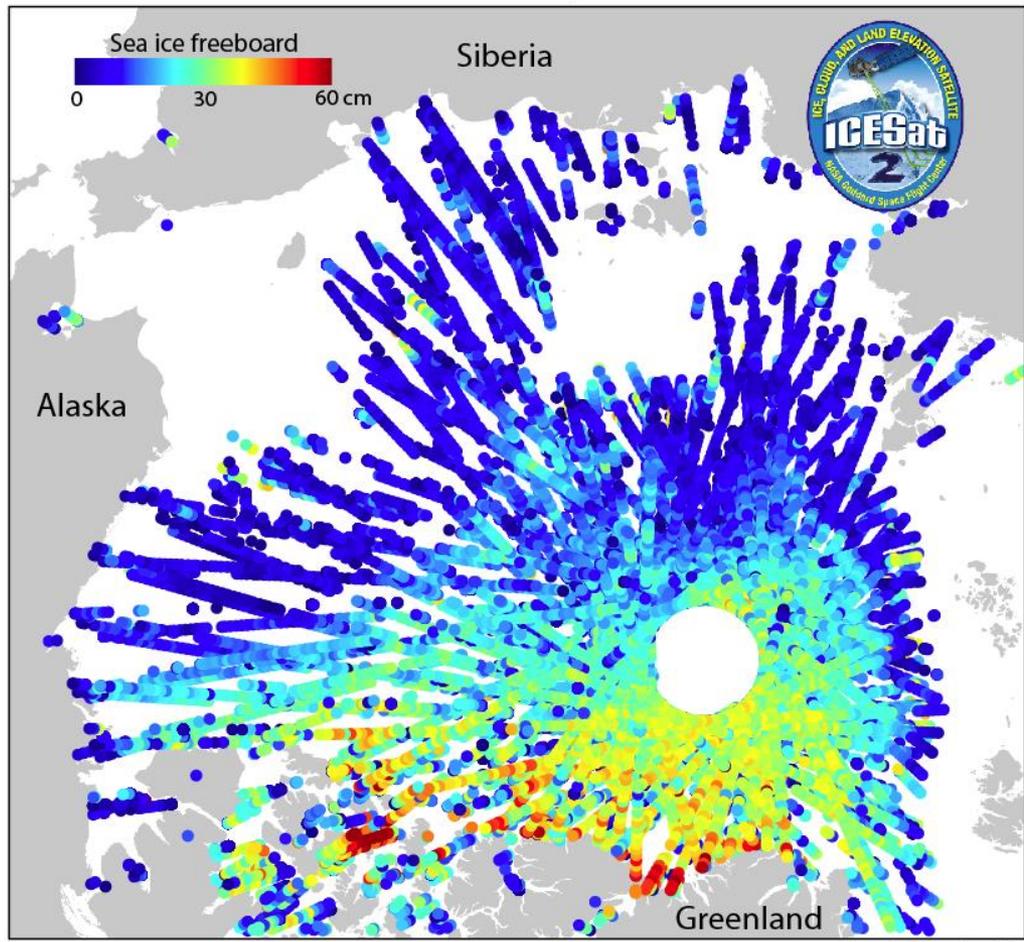
9/10ths of sea ice is below the water line.  
This opens up the third dimension:  
sea ice thickness



# What DOES the data look like?



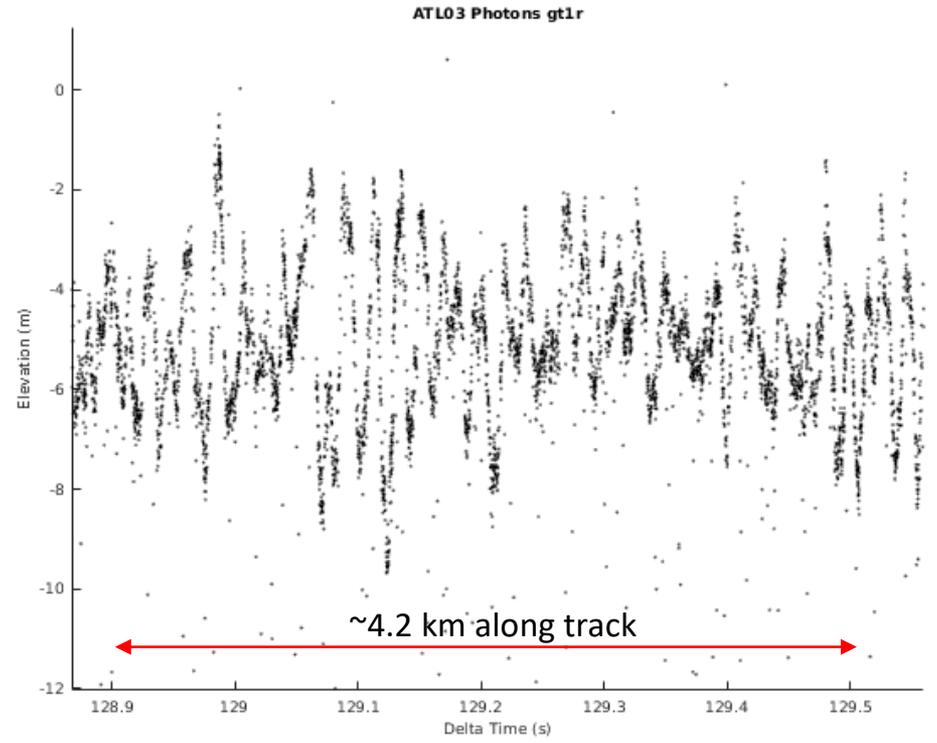
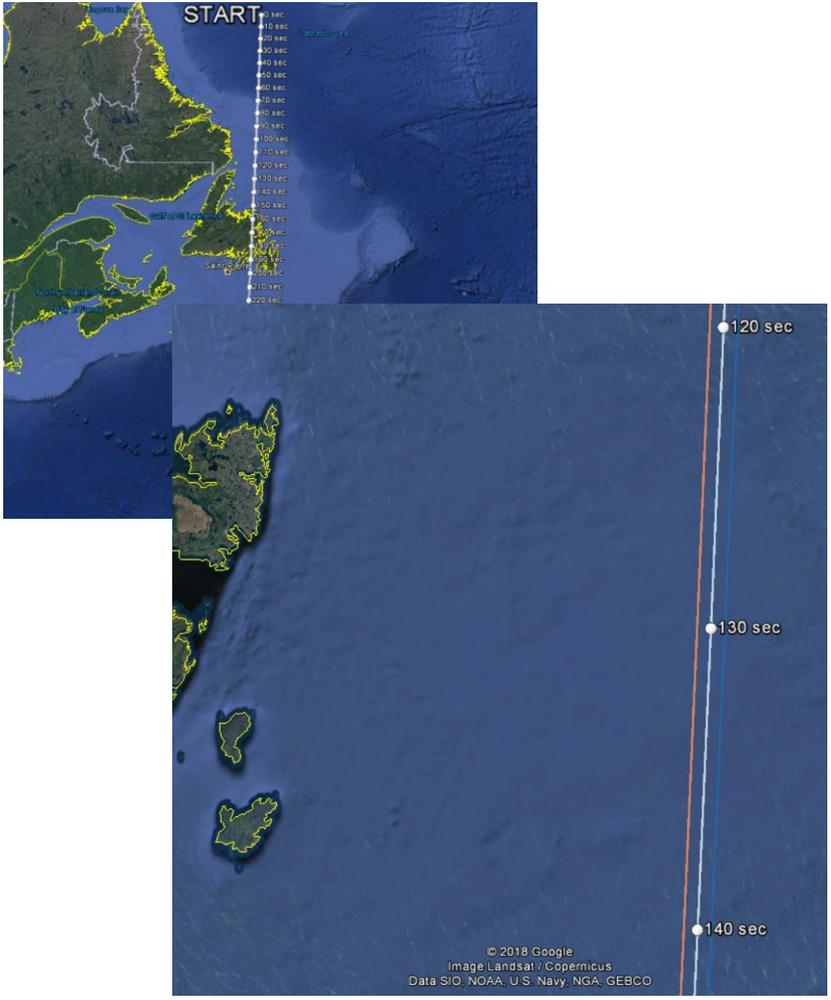
Oct 14 - Oct 28, 2018



Sea Ice Freeboard of the Arctic Ocean in the Late Fall from 14 days of ICESat-2 data

# What DOES the data look like?

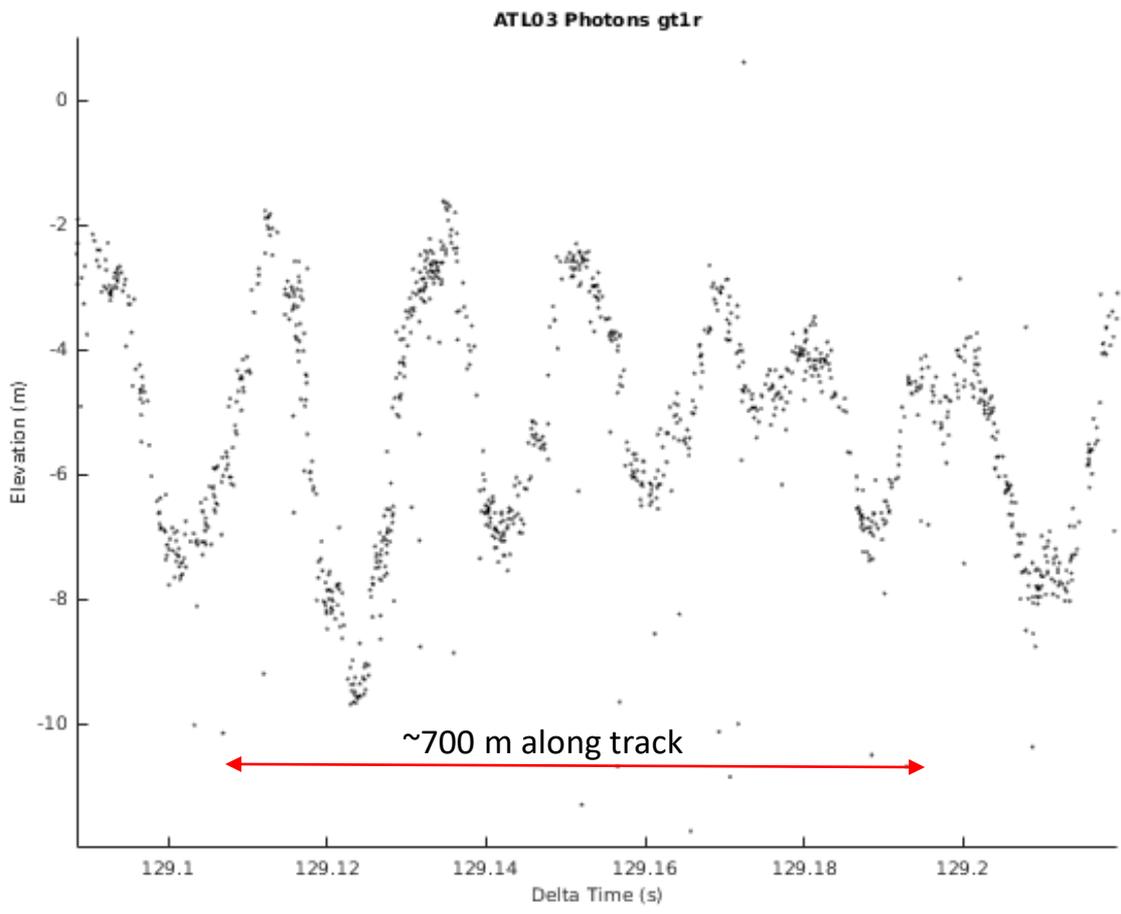
Example from 17 October, Start time 070948 UTC



Ocean Waves



# What DOES the data look like?



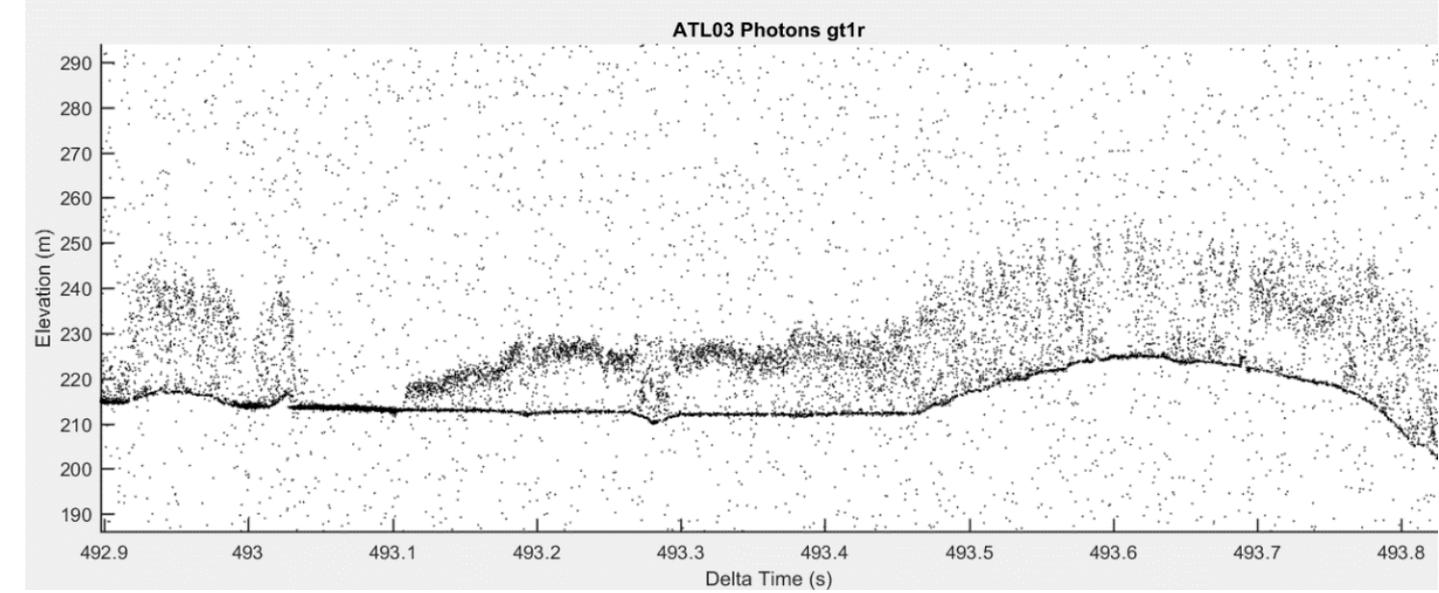
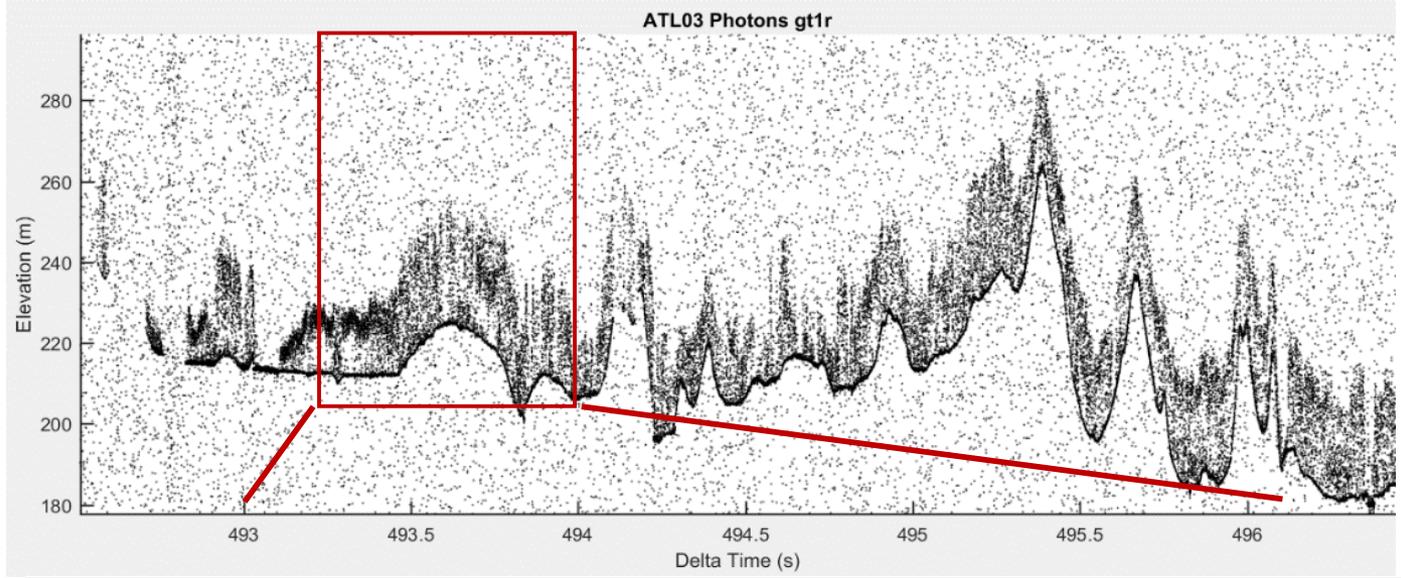
- With the strong beams, there is a well defined wave structure
- This example depicts wavelengths on the order of 140 m

Ocean Waves

Figures courtesy of Brad Klotz

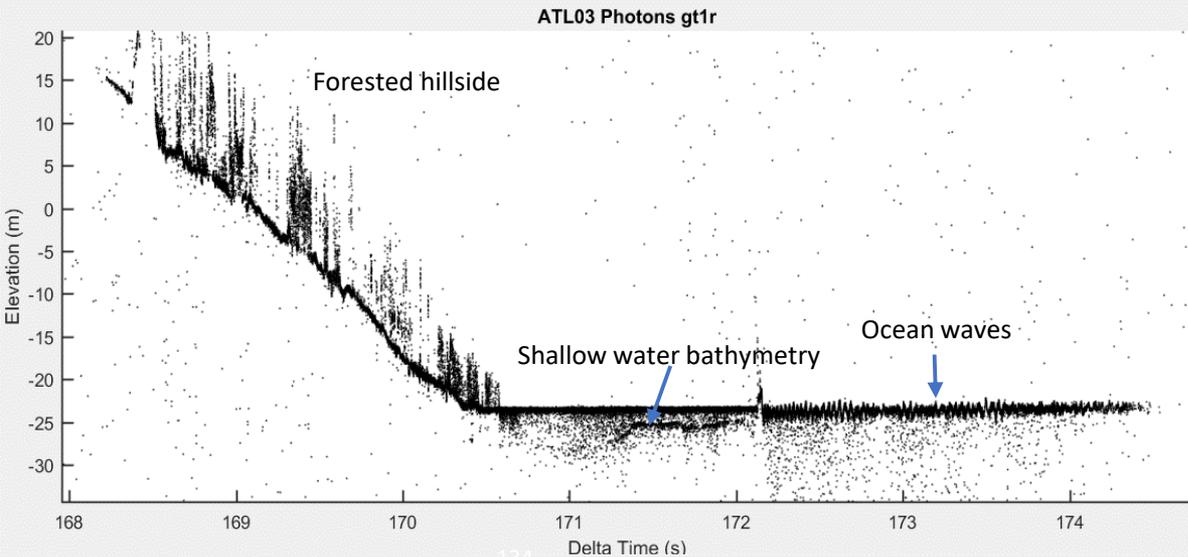


# What DOES the data look like?

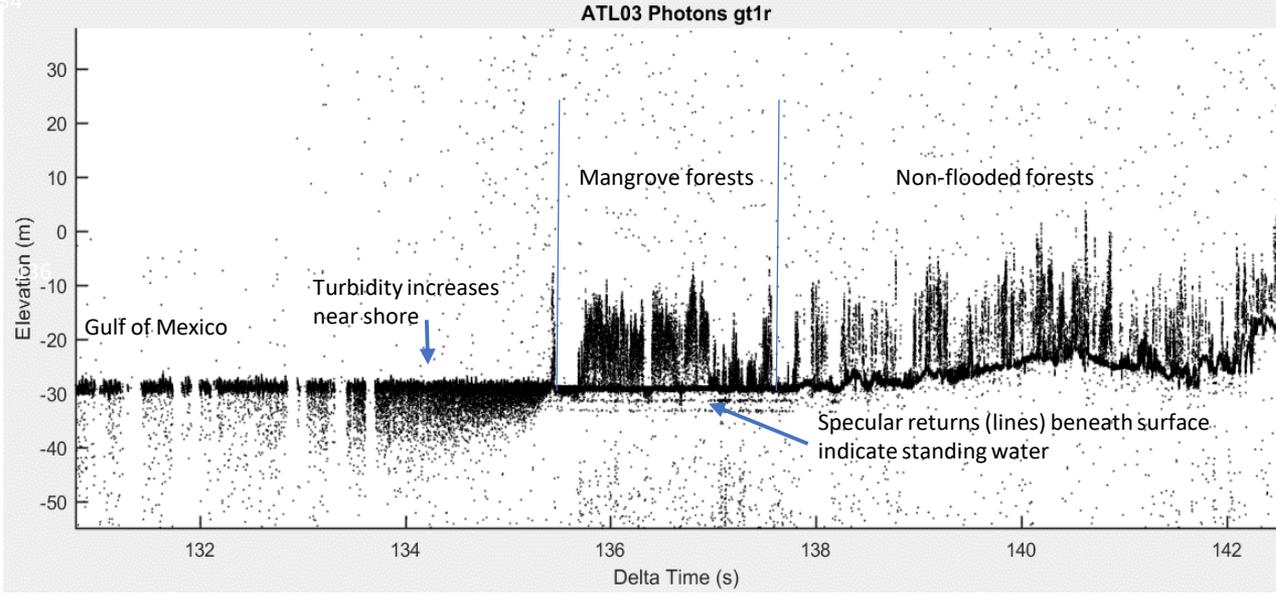
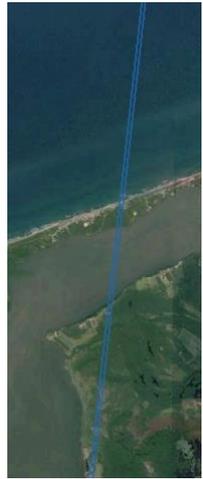




# What DOES the data look like?

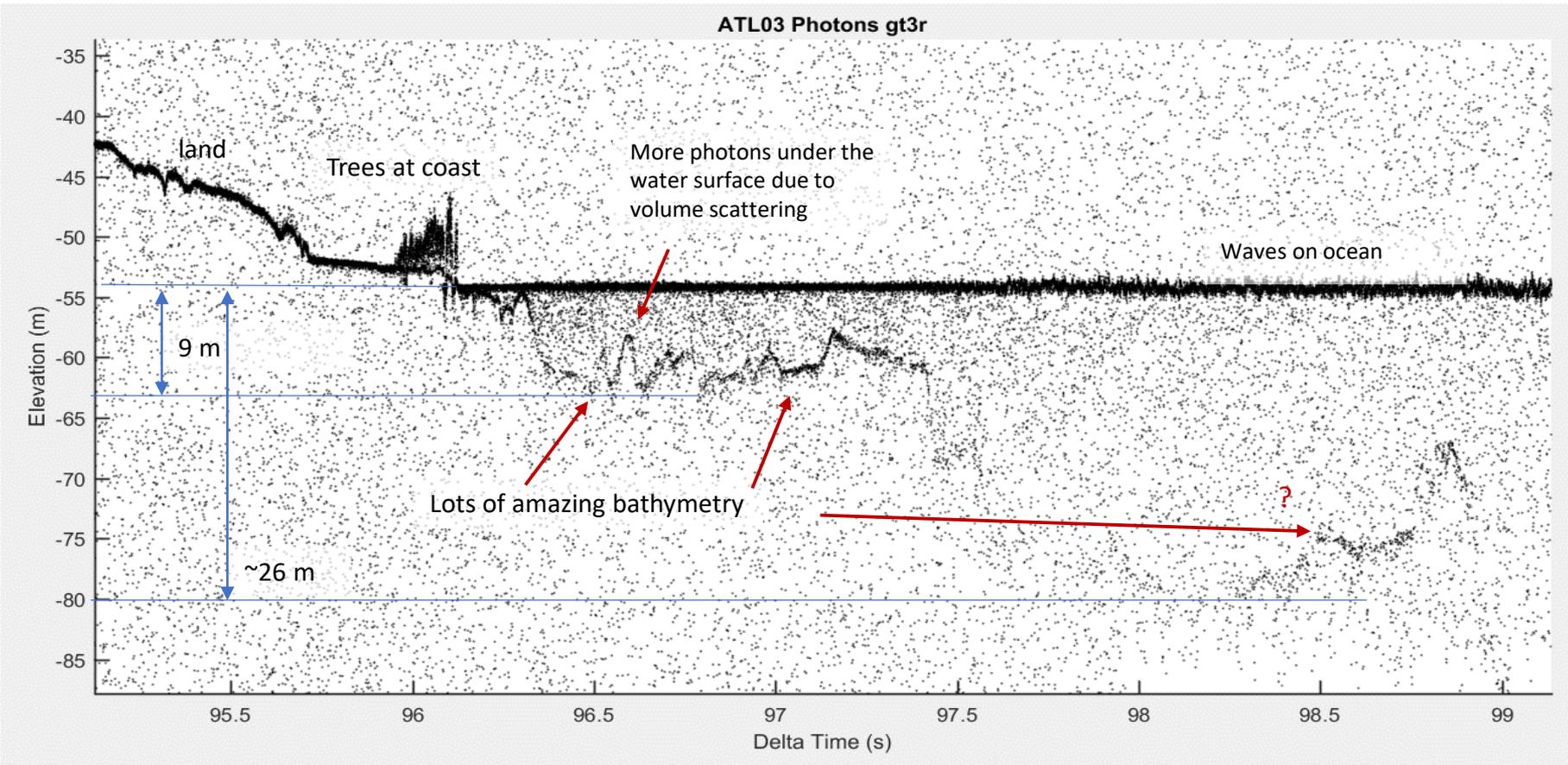


Ground track through Mexico. Mountains in interior are cloud covered, but coastal areas are cloud-free





# What DOES the data look like?



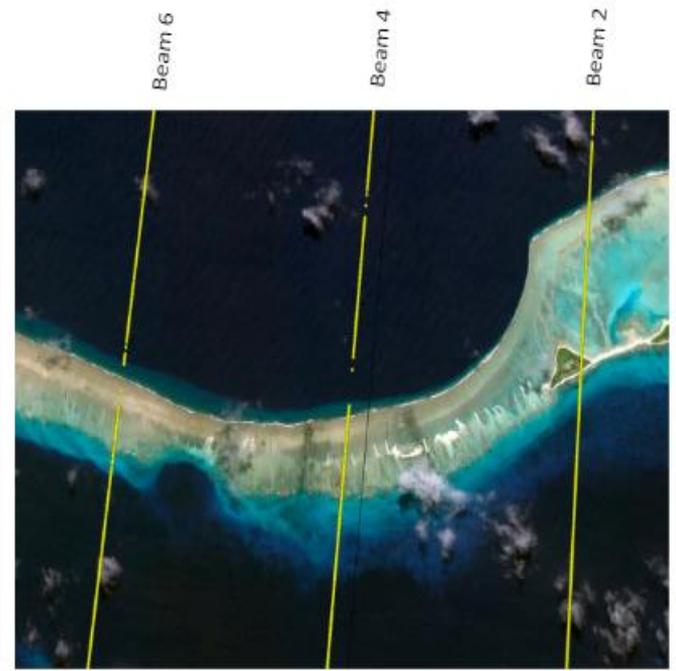
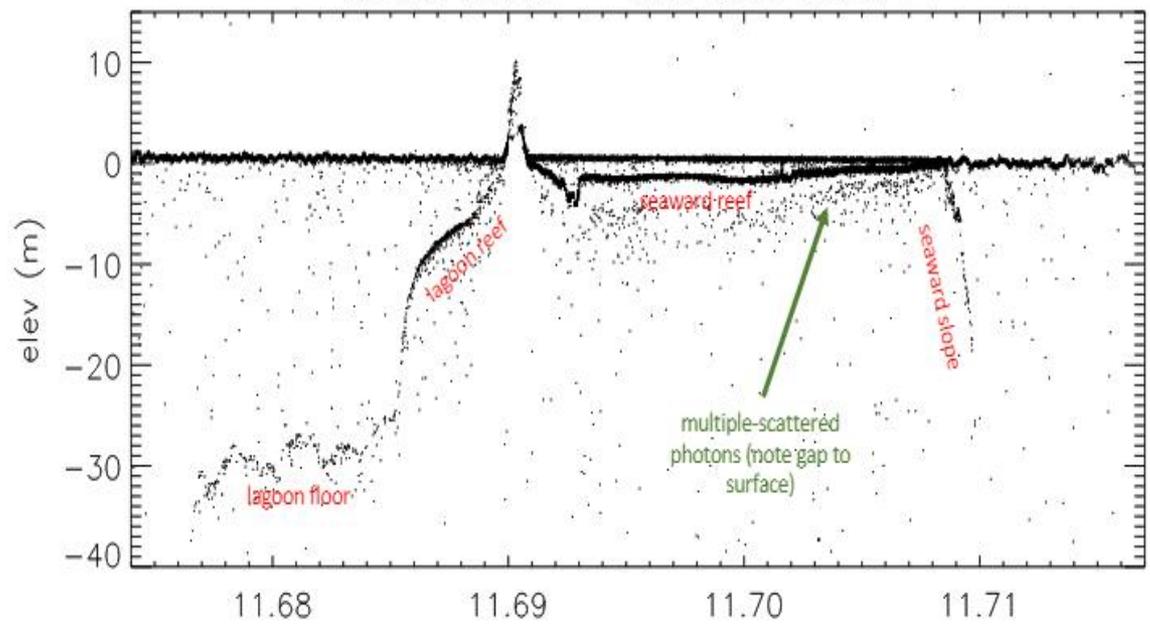


# What DOES the data look like?



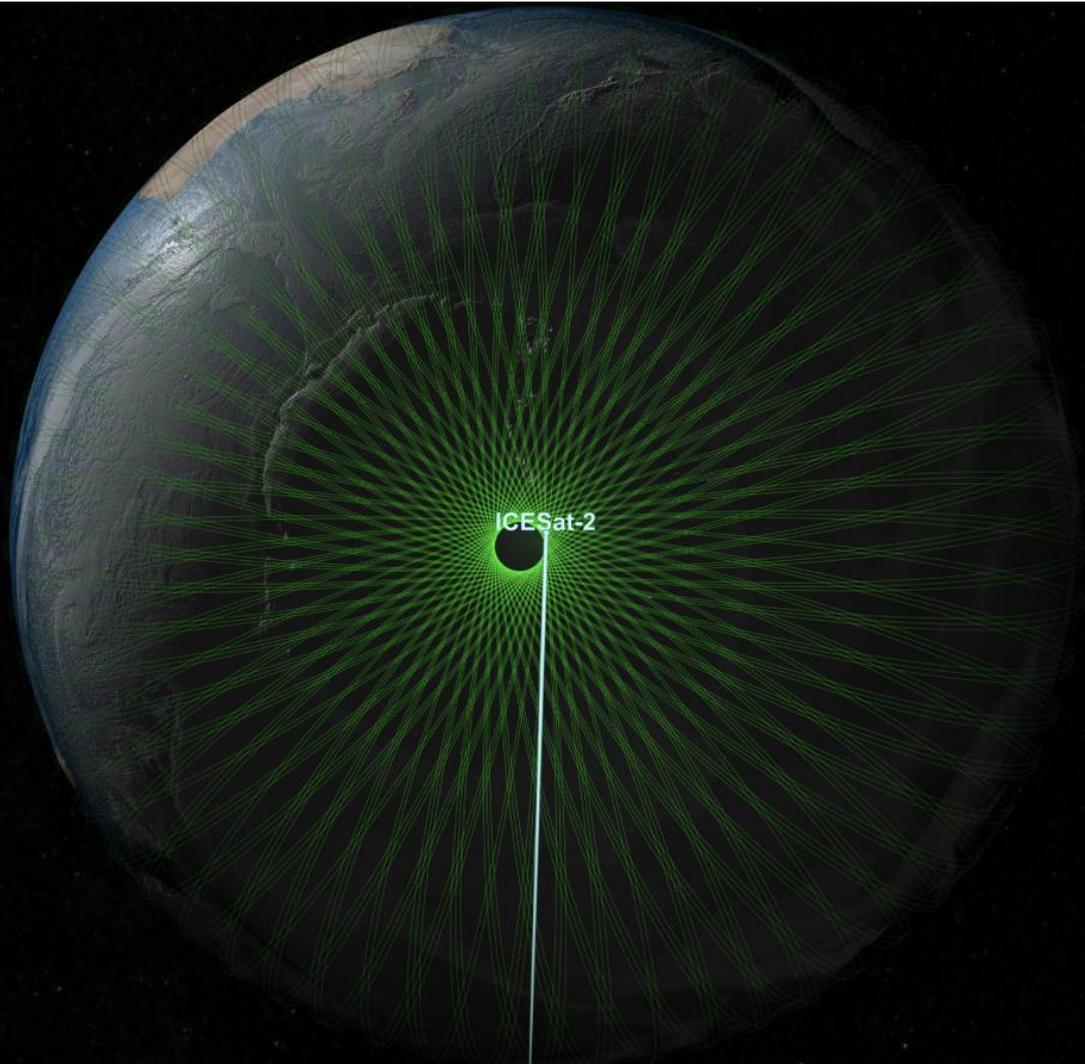
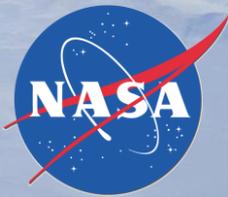
RGT 306 – Bikini Atoll

BIKINI ATOLL – RGT 306 BEAM 2





# ICESat-2 Pole Hole





# ICESat-2 Pole Hole



## 87.979S Traverse for ICESat-2 validation:

Annual traverse, next 4 years

300 km along 87.979S (*long length scale*)

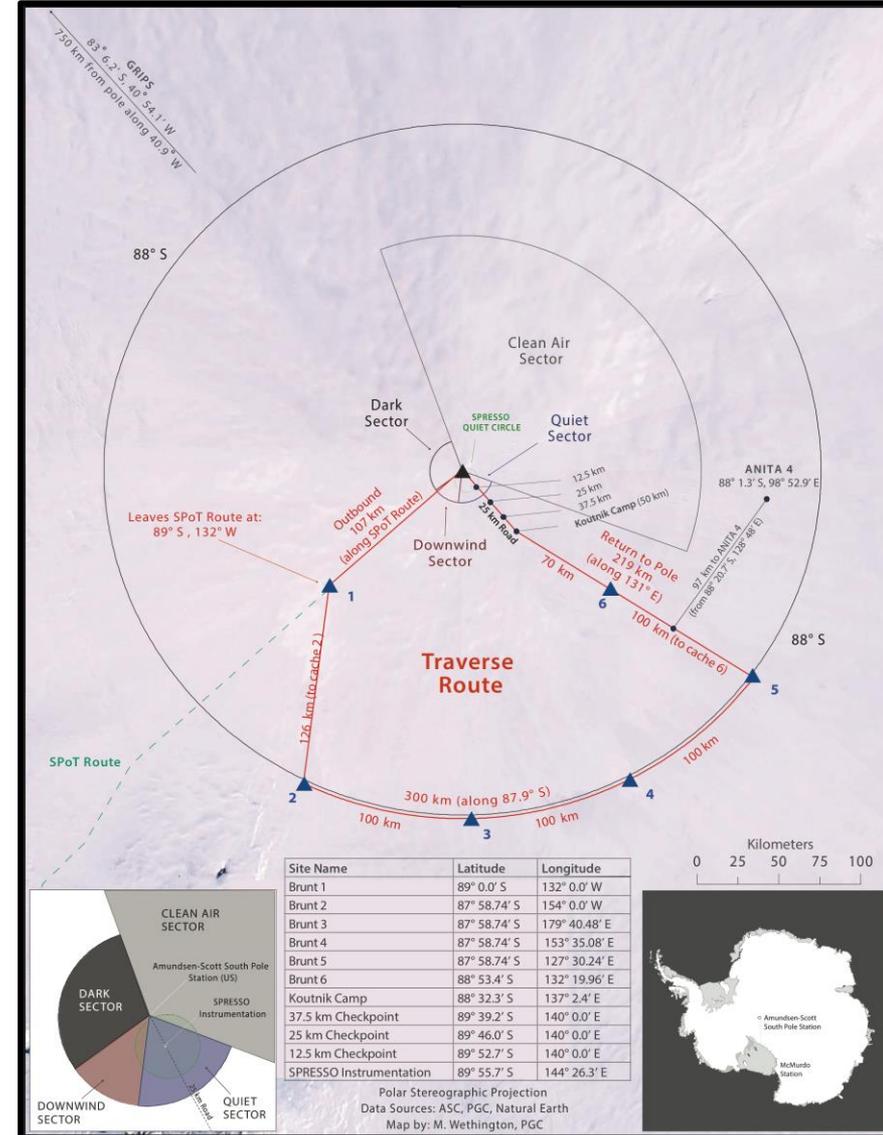
Intersects 277 of 1387 ICESat-2 ground tracks

20% of the ICESat-2 tracks (*long time scale*)

Survey-quality GPS data

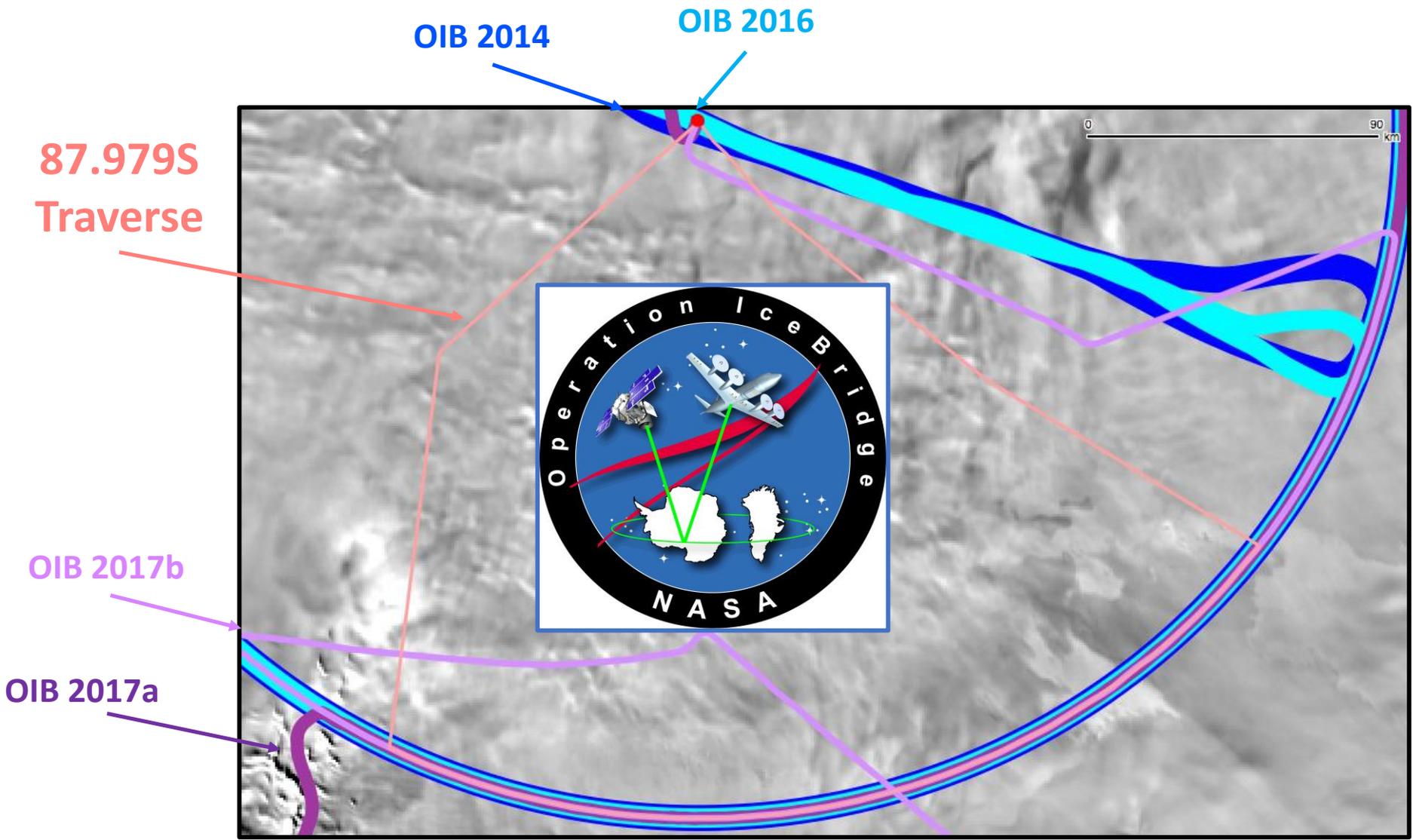
PPP post-processing

<1 cm accuracy and  $< \pm 8$  cm precision





# 87.979S and Operation IceBridge



87.979S  
Traverse

OIB 2014

OIB 2016

OIB 2017b

OIB 2017a



# ICESat-2 Pole Hole





# ICESat-2 Pole Hole



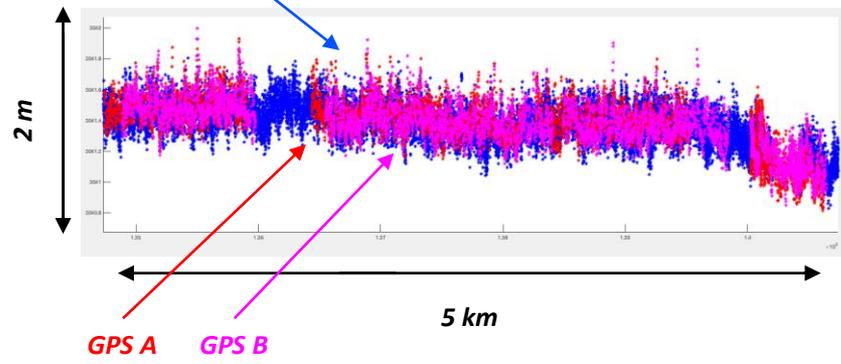


# ICESat-2 Pole Hole

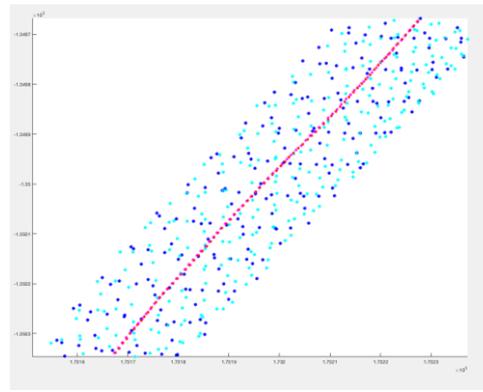


**GPSA vs GPSB:  $1.6 \pm 4.1$**   
**GPS vs ATM:  $-2.7 \pm 14.1$**

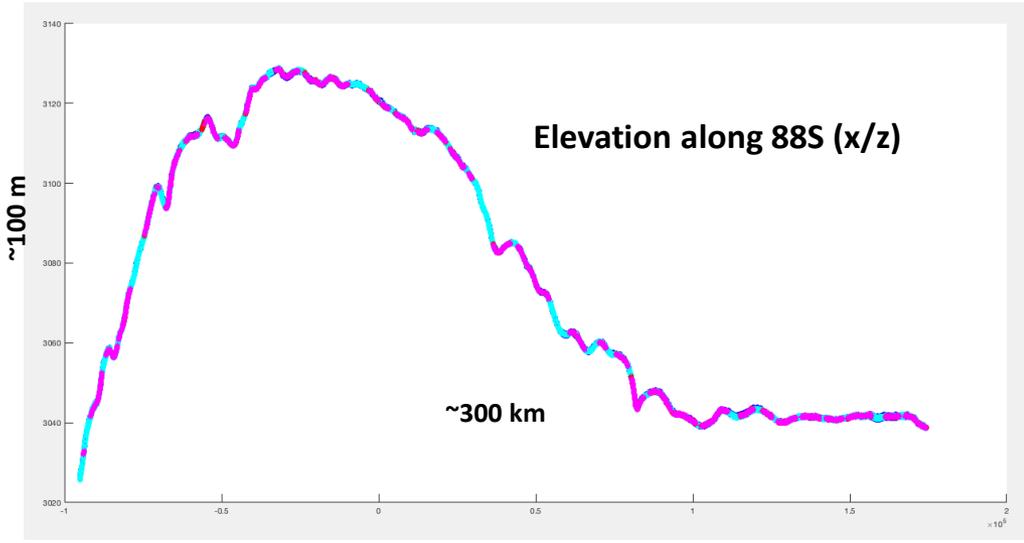
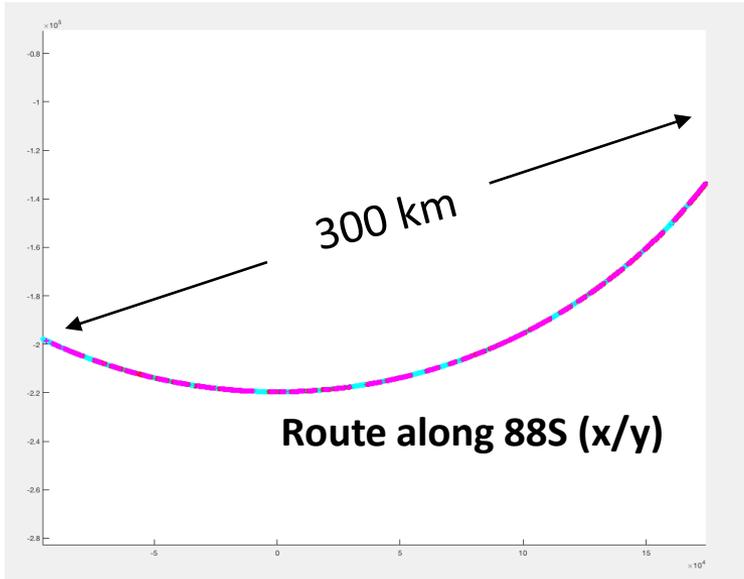
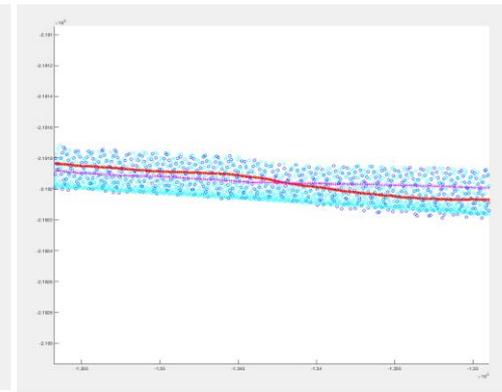
ATM 2014



In each other's tracks



Crossing each other's tracks





# The Future is Here!



The beginning of a new era in polar science begins!

GRACE Follow On is now up and running after some initial issues.  
ICESat-2 is well on it's way to nominal science data production.

