The NASA Ice, Cloud and land Elevation Satellite (ICESat) Series: Science, Data Products and Operations

B. E. Schutz and H. Rim
University of Texas at Austin
schutz@csr.utexas.edu
T. Neumann and S. Luthcke
GSFC

Laser Ranging Workshop, Annapolis, MD October 27-31, 2014

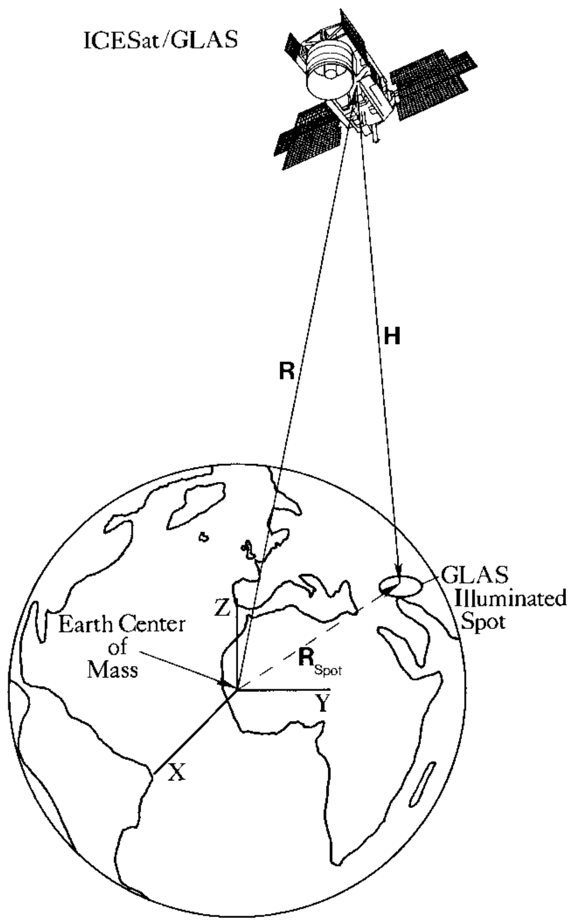
NASA Spaceborne Laser Altimetry

- Examples:
- Altimetry is one manifestation of laser ranging
- Early laser altimetry from Shuttle and even earlier from Apollo
- Laser altimetry at Mars (MOLA)
- MESSENGER (Mercury)
- Earth satellite series
  - Ice, Cloud, and land Elevation Satellite (ICESat or ICESat-1)
  - Follow-on mission ICESat-2
- Others
- Focus of this presentation will be ICESat series

ICESat

- **I**ce, **C**loud and land **E**levation **Sat**ellite
  - Launched January 13, 2003 00:45 UTC from Vandenberg (CA) on Delta-2
  - Delta-2 will be used for launch of ICESat-2, expected launch ~October 2017
- Primary instrument
  - on ICESat was GLAS (Geoscience Laser Altimeter System)
  - new instrument for ICESat-2 called ATLAS (Advanced Topographic Laser Altimeter System)
- Purpose:
  - detect surface change of polar ice sheets and sea ice,
  - map land topography and vegetation canopy with high accuracy
  - profile clouds and aerosol layers
- Construction:
  - GLAS and ATLAS are NASA Goddard instruments
  - ICESat-1spacecraft built by Ball Aerospace (Boulder)
  - ICESat-2 spacecraft built by Orbital Sciences (Phoenix)

Satellite Altimetry Concept: I



- Altimeter (radar or laser) measures the scalar distance from the spaceborne instrument to a point on the planet surface illuminated by the instrument; hence the planet topography is described with respect to the satellite orbit
- Topography with respect to a fixed planetary reference point and axes is required
- If the following are known/ measured: **R** and **H**, it follows that the measured point on the surface is given by $\mathbf{R}_{\mathbf{spot}} = \mathbf{R} + \mathbf{H}$, i.e., the geolocated spot; knowledge of POD and PPD are important

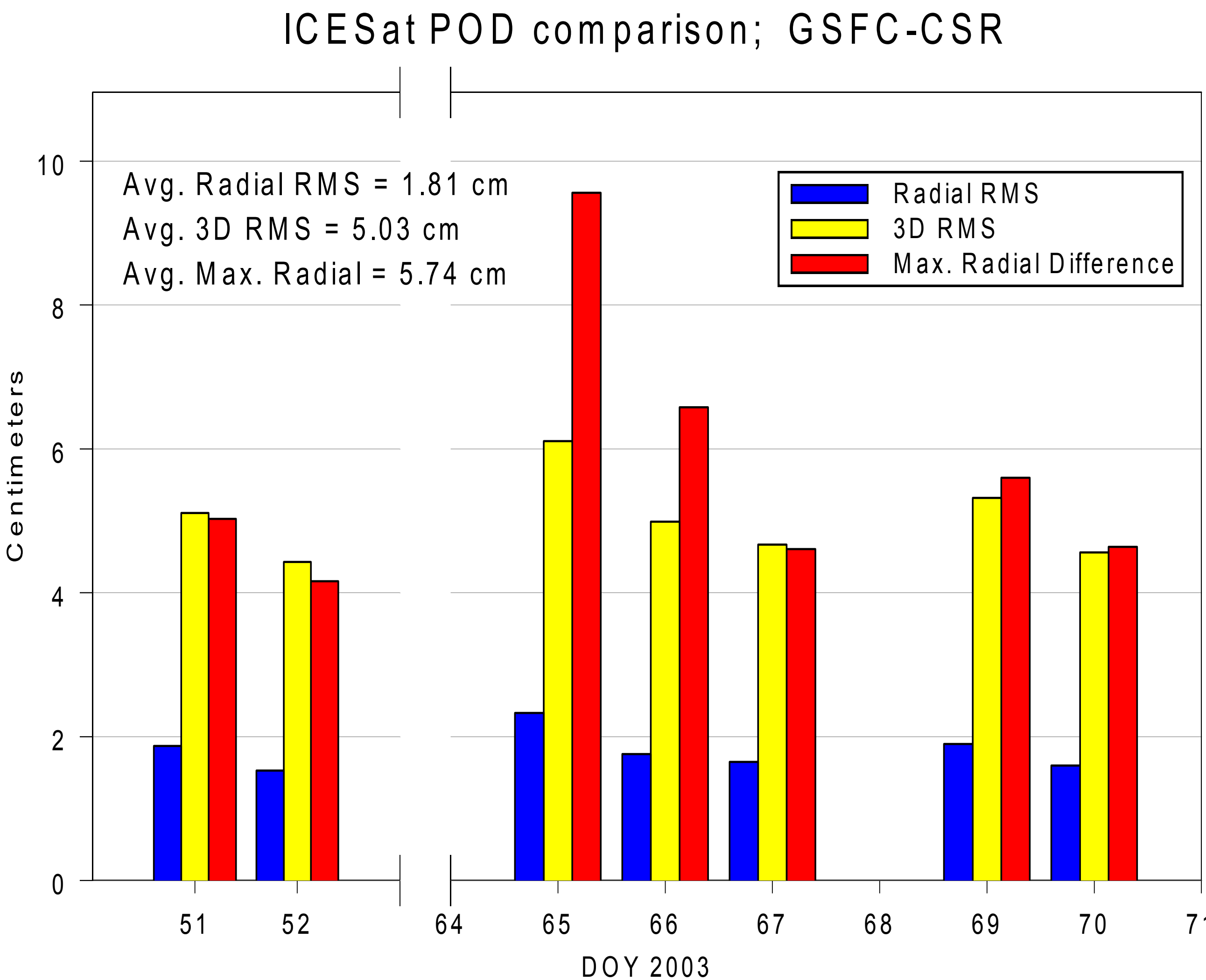
Satellite Altimetry Concept: II

- Determination of surface topography requires POD and PPD
- POD for ICESat-1 and -2 based on GPS (ICESat-1 is JPL BlackJack receiver; ICESat-2 is RUAG receiver)
- SLR provides **important** validation of orbit determined from GPS (reduces the need for ~ continuous observations, which can be difficult with SLR)
- Experience with ICESat-1 SLR showed that POD accuracy was ~2 cm

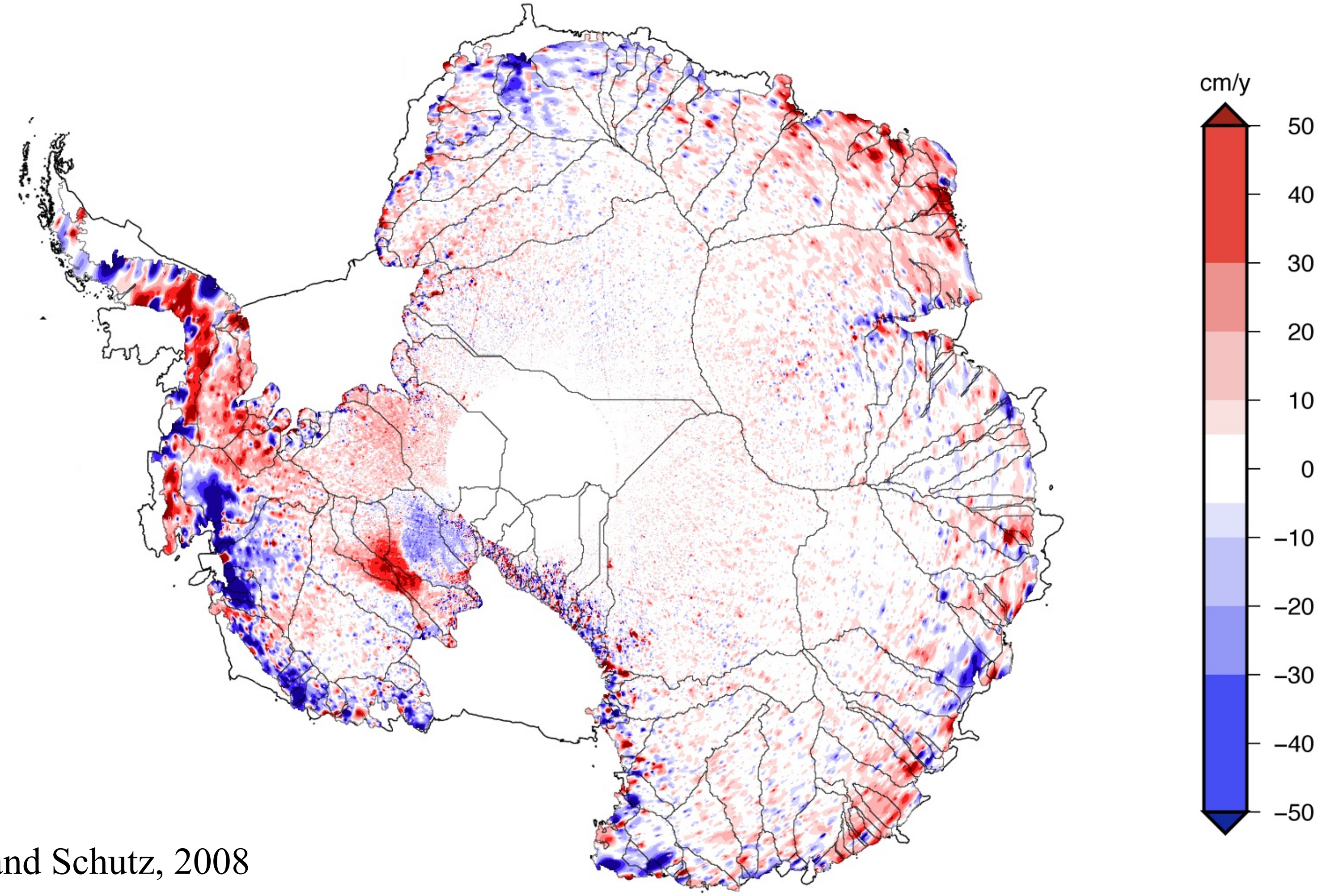
SLR Reflector on ICESat-1 and -2

- ICESat-1 SLR array designed and constructed by ITE in Laurel, MD
- ICESat-2 SLR array very similar to ICESat-1 and has been delivered to Orbital Sciences for installation

NASA/GSFC698 and UTCSR ICESat-1 POD Cal/Val

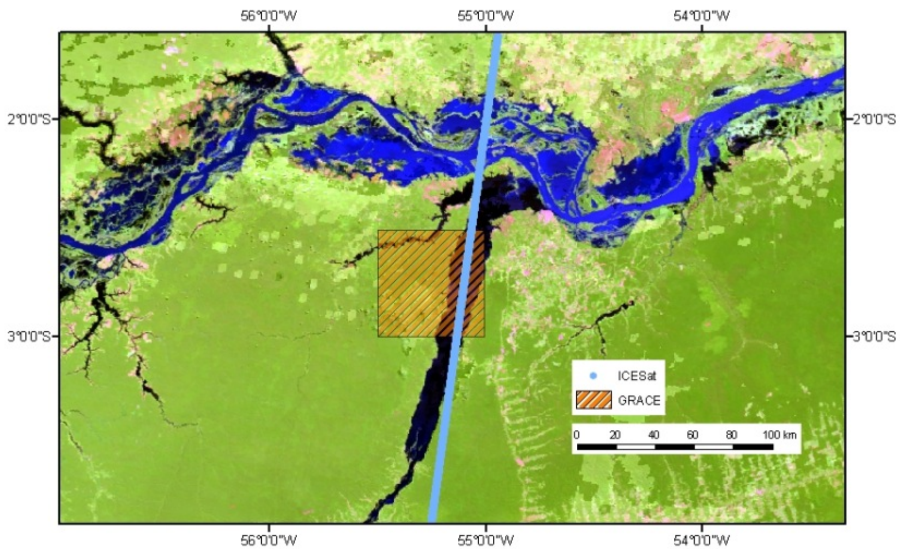


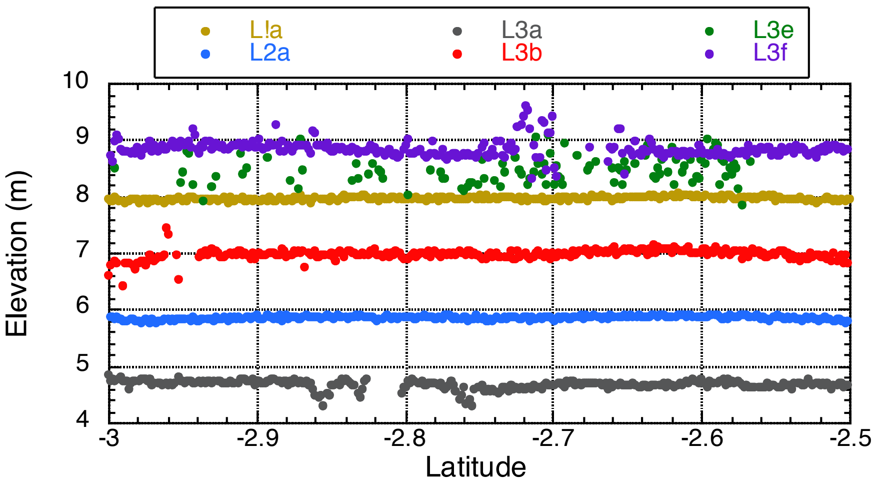
Changes in Antarctica from ICESat



Urban and Schutz, 2008

Other Applications: Rio Tapajos (Brazil) ICESat Monitoring





- ICESat measures 5-9 m elevation change
- Very small slope of river consistent with hydrology
- Noise from laser passing through clouds above the river
- Seasonal river stages and temporal phase closely match data from other sources

Status and Future

- ICESat-1 deorbited in 2010 to reduce possible contribution to orbital debris (deorbited at end of instrument life)
- ICESat-2 plans moving forward, with plans to launch in ~October 2017 on Delta-2
  - ICESat-2 under development by Orbital Sciences Corp. (in test)
  - Lower altitude than ICESat-1 (~100 km)
  - ICESat-2 will have much higher repetition rate than ICESat-1; smaller footprint
  - ICESat-2 uses European GPS receiver (RUAG)
- Time series of elevation change important, so several year gap in time series will be partially filled by collection of airborne lidar data (Operation IceBridge)

Status and Future

- Concern about illumination of ICESat-1 detectors by ground-based lasers (SLR) led to development of SLR tracking restrictions
  - Most commonly used restriction for ICESat-1 was an elevation angle restriction of 70 degree cutoff;
  - Other restrictions available, such as a “go/no-go” restriction, which gives a mission control center the ability to enact a global restriction on ranging to its target
  - Specific nature of restrictions for ICESat-2 under investigation by ATLAS developers at GSFC

Other Differences between ICESat-1 and ICESat-2

	ICESat-1	ICESat-2
Orbit		
Inclination	94 degrees	92 degrees
Altitude	~600 km	~500 km
Repeat	91d with 33d sub-cycles	
Laser		
Frequency	IR and green	Green only
Beams	1 beam	6 beams
Rate	40 Hz	10,000 Hz
Measurement	Echo digitization (waveform)	Photon counting

Other Differences between ICESat-1 and ICESat-2

- Data Products

ICESat-1
GLA01 Waveform
GLA02 Global Atmosphere
GLA03 Engineering
GLA04 Pointing
GLA05 Corrected Range
GLA06 Global Elevation
GLA07-11 Atm products
GLA12 Ice sheets
GLA13 Sea ice
GLA14 Land
GLA15 Ocean

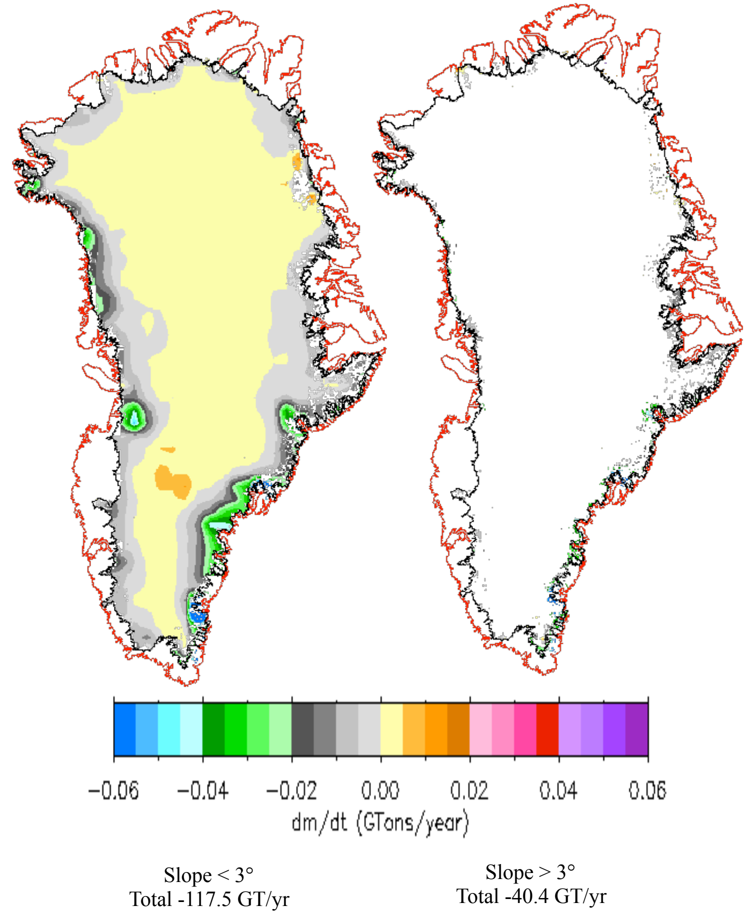
ICESat-2
ATL01 Level 1A product
ATL02 Instrument corrected data
ATL03 Global geolocated photons
ATL04,09 Atmosphere products
ATL06,11,14,15 Land ice H and dH
ATL07,10 Sea ice SSH, freeboard
ATL08 Land and vegetation
ATL12 Ocean
ATL13 Inland water

ICESat derived ice sheet elevation change

ICESat-derived ice loss as a function of slope

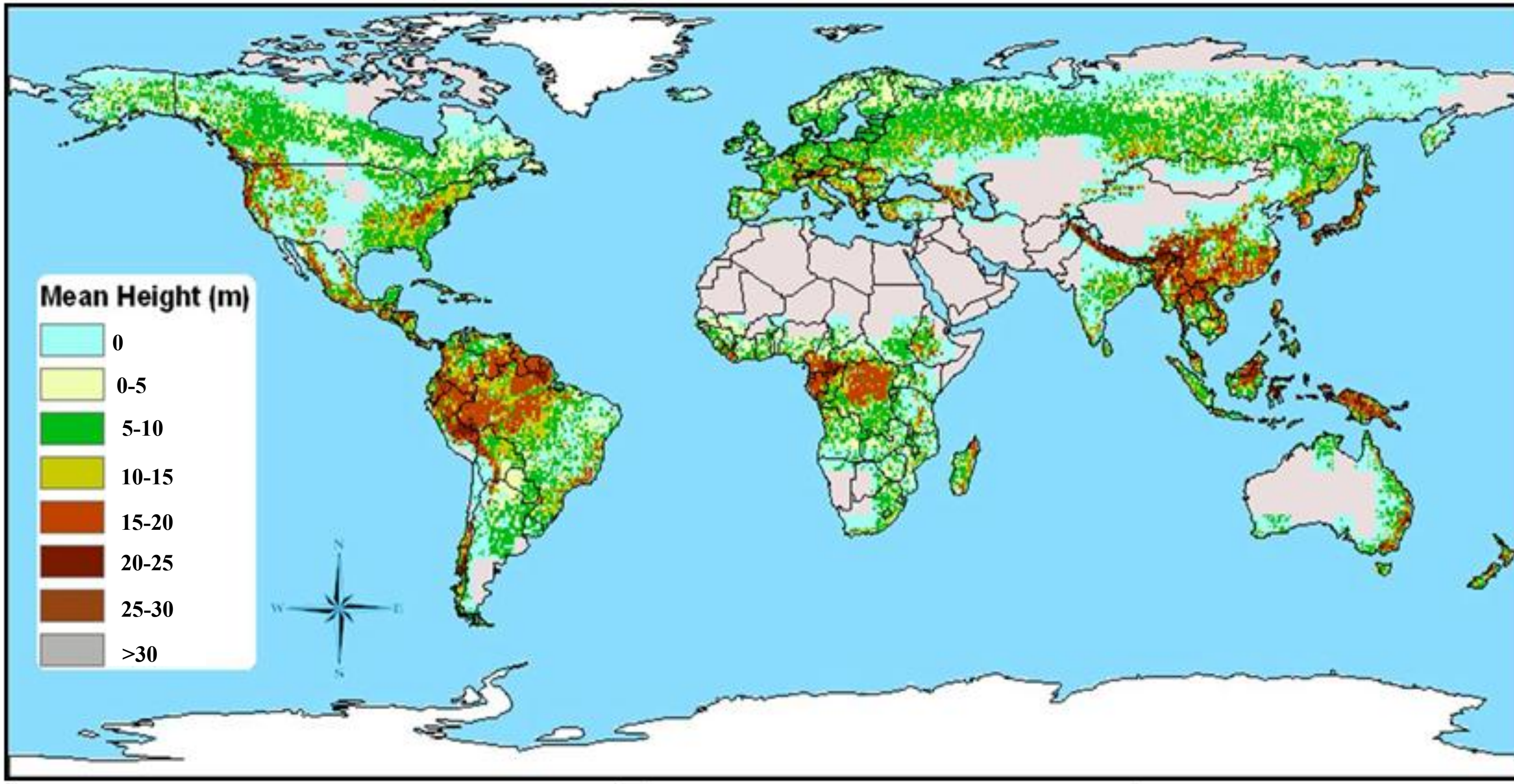
Slope	Fraction of area	Estimated Mass Loss	Total Ice Sheet Loss	Fraction of Total
>0.5°	33%	175 GT	145 GT	>100%*
>1°	18%	132 GT	145 GT	83%
>2°	8.5%	68 GT	145 GT	43%
>3°	5.1%	40 GT	145 GT	26%

* there is a net gain of ice in areas with slopes <0.5°



Zwally and Saba (2009)

ICESat measured canopy height

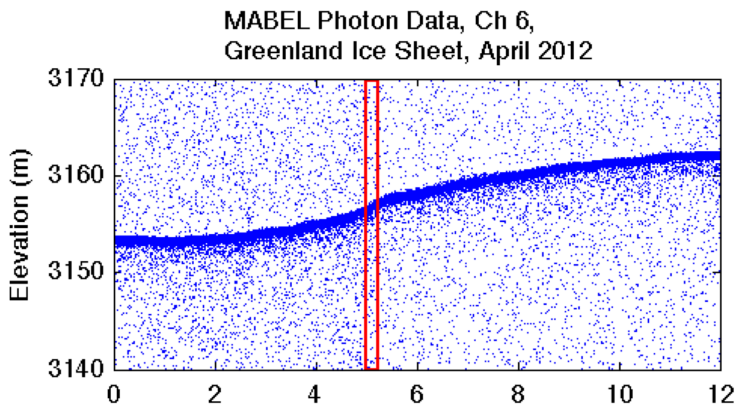


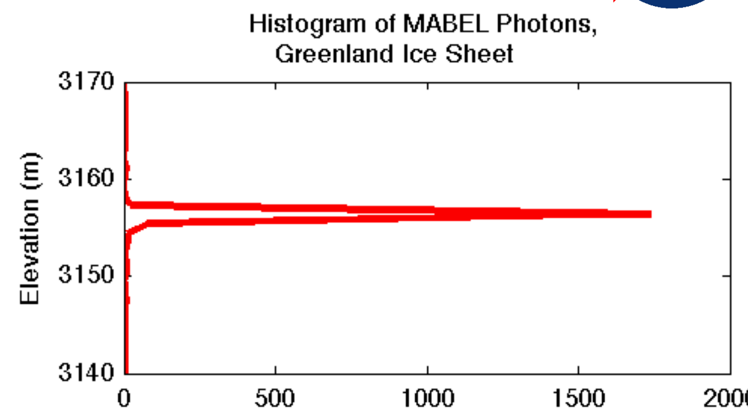
- ICESat's accurate ranging capability has provided large-scale global biomass estimates from canopy height measurements.
  - 50-70 meter footprint provides about 5 m average height accuracy.

Lefsky et al., 2010

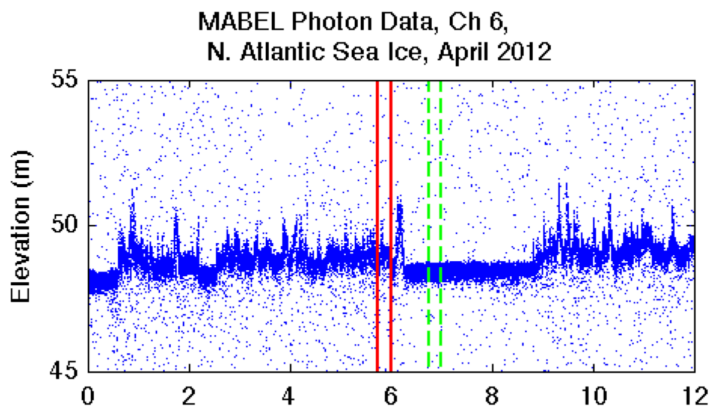
What will the ICESat-2 data look like?

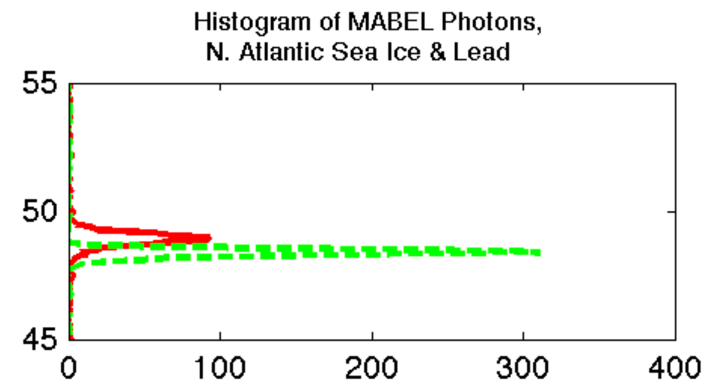
Ice sheets:





Sea ice





Vegetation