ICESat-2: Measuring the Height of Earth One Photon At a Time

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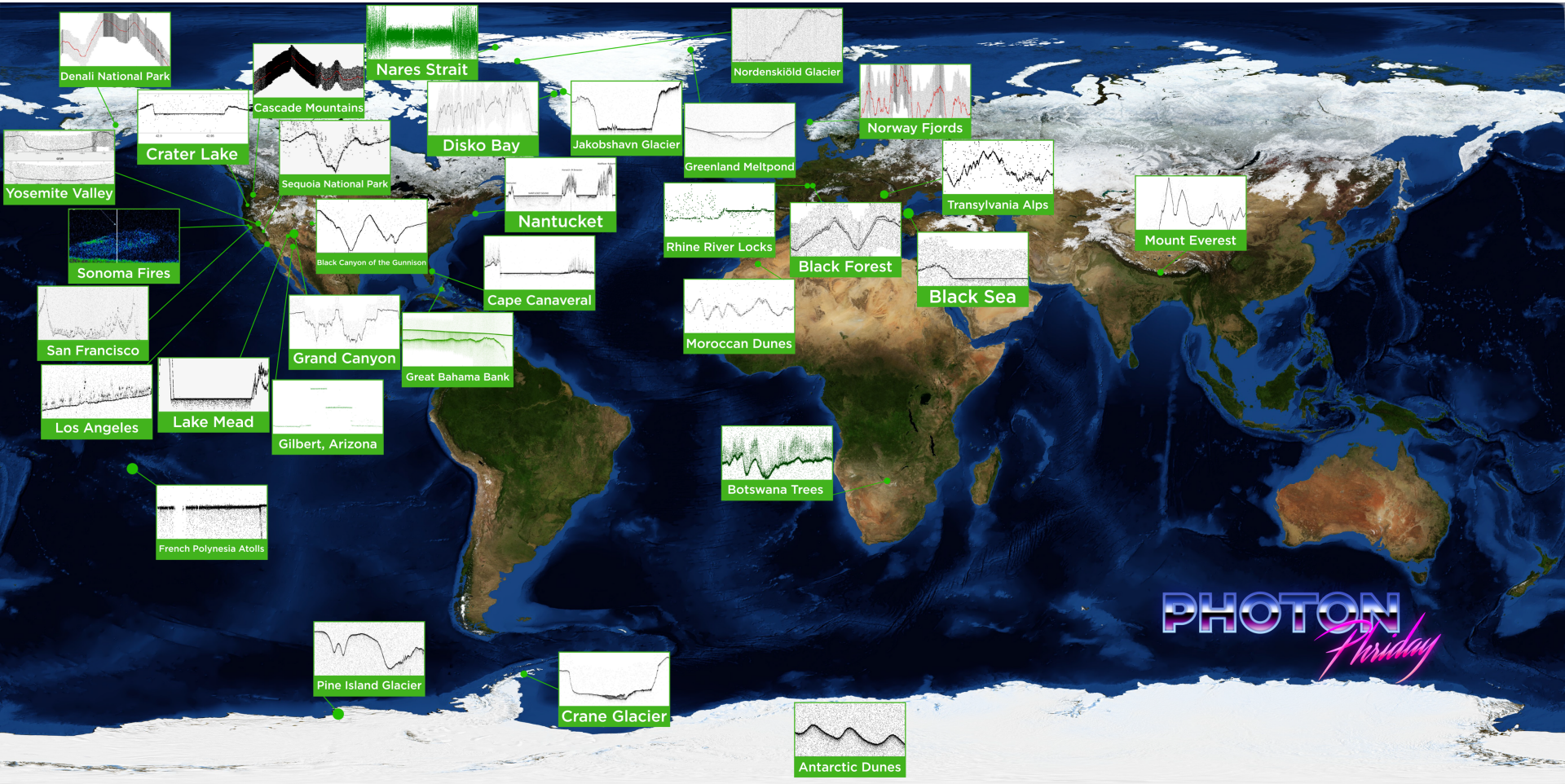
NASA Goddard Space Flight Center
On behalf of the entire ICESat-2 Science Community

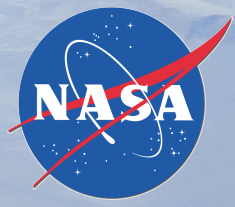
Covering the world with soothing green light

ICESat-2
ICE, CLOUD, AND LAND ELEVATION SATELLITE

NASA



ICESat-2 Objectives



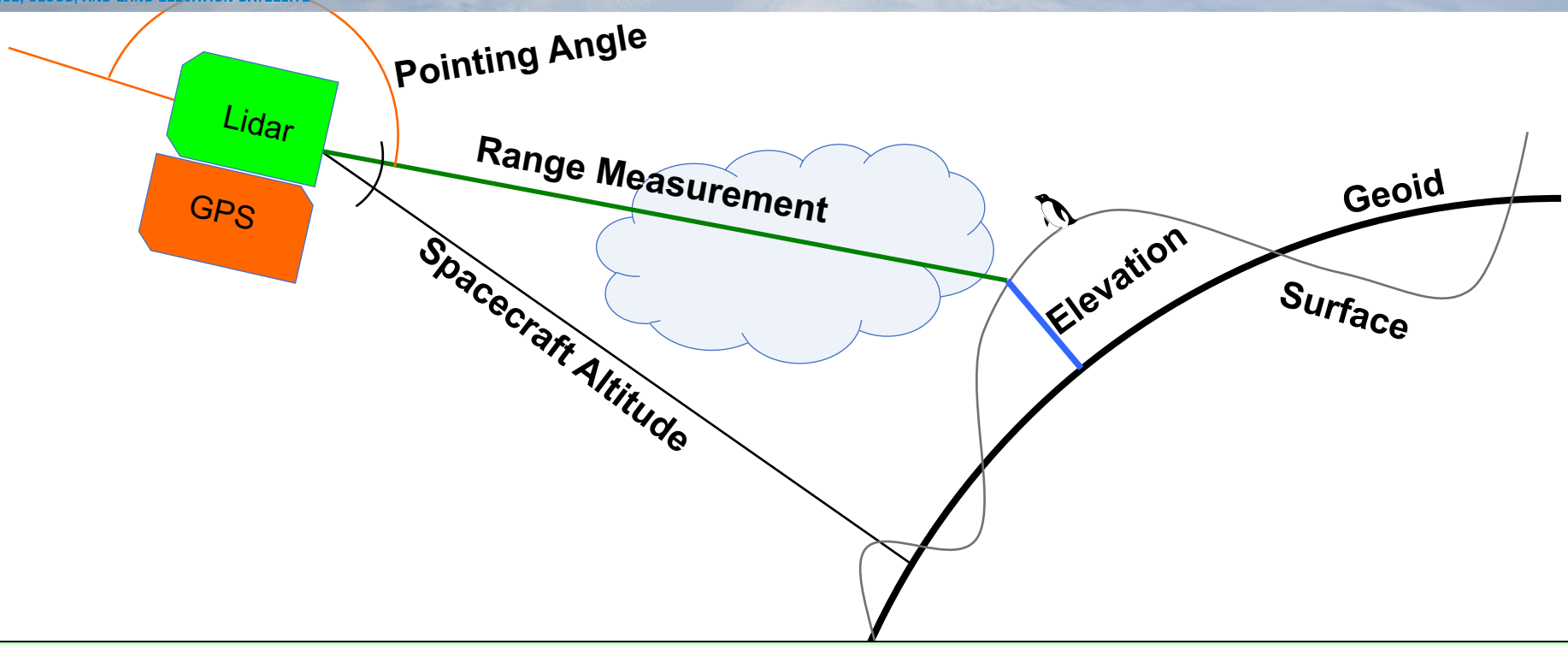
Quantify polar ice-sheet contributions to current and recent sea-level change and the linkages to climate conditions

Quantify regional signatures of ice-sheet changes to assess mechanisms driving those changes and improve predictive ice sheet models; this includes quantifying the regional evolution of ice sheet change, such as how changes at outlet glacier termini propagate inward.

Estimate sea-ice thickness to examine ice/ocean/atmosphere exchanges of energy, mass and moisture;

Measure vegetation canopy height as a basis for estimating large-scale biomass and biomass change.

ICESat-2 Measurement Concept



We want to measure **elevation**

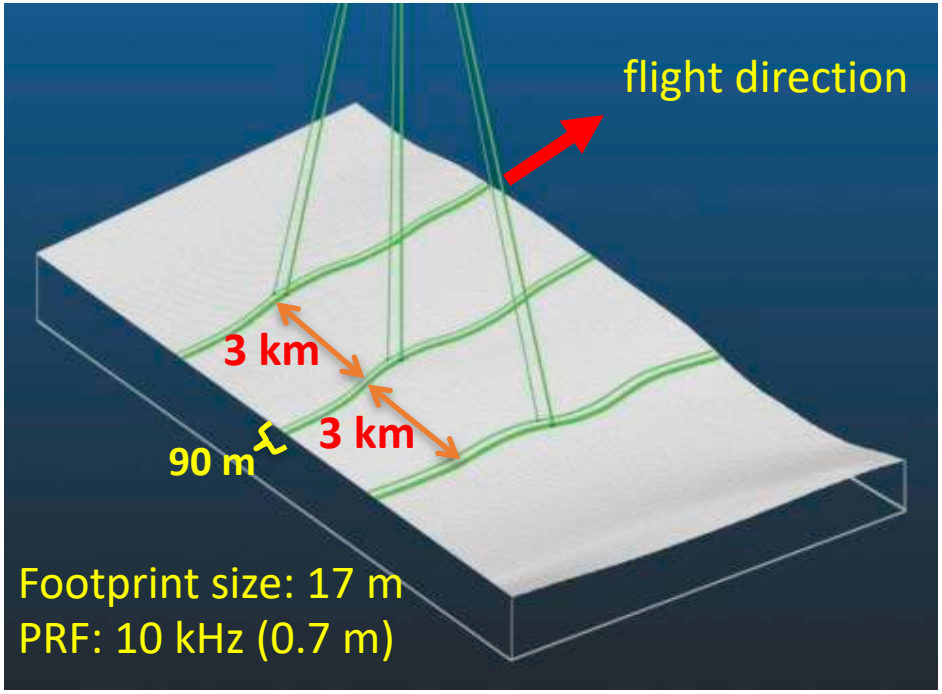
Lidar measures **range (time of flight)** and **absolute pointing angle**

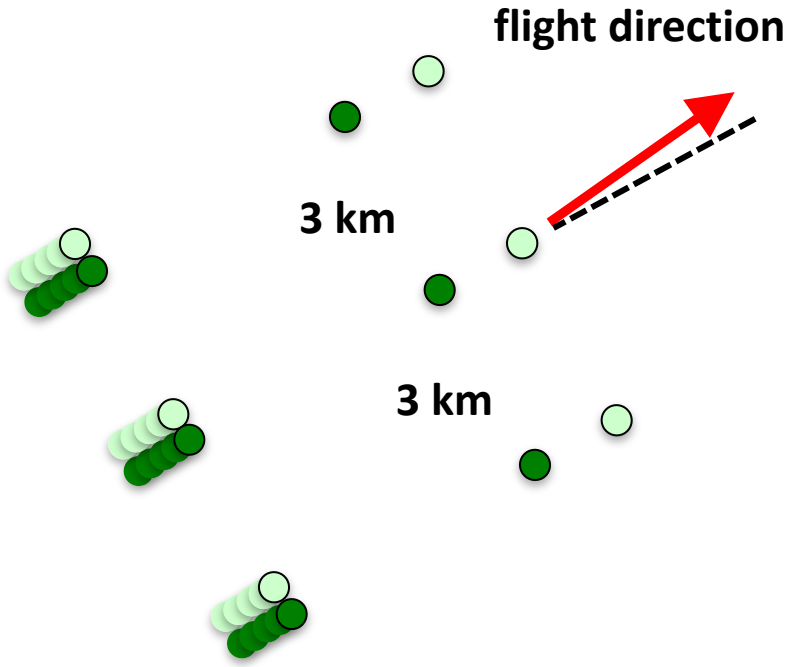
GPS measures position in orbit

Ground processing puts the pieces together

ICESat-2 Measurement Concept

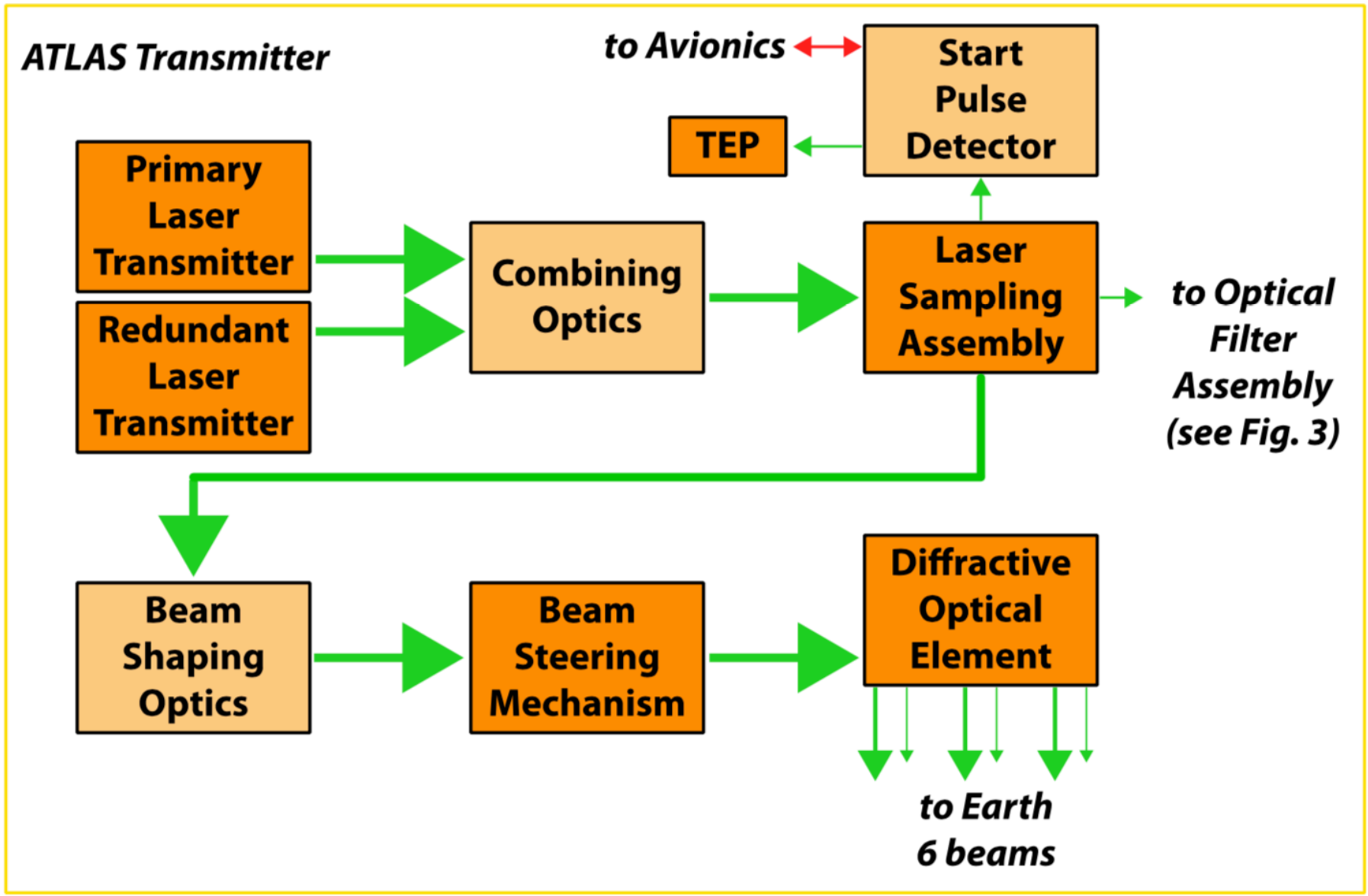
Single laser pulse at 532nm, split into 6 beams. Single-photon sensitive detection.



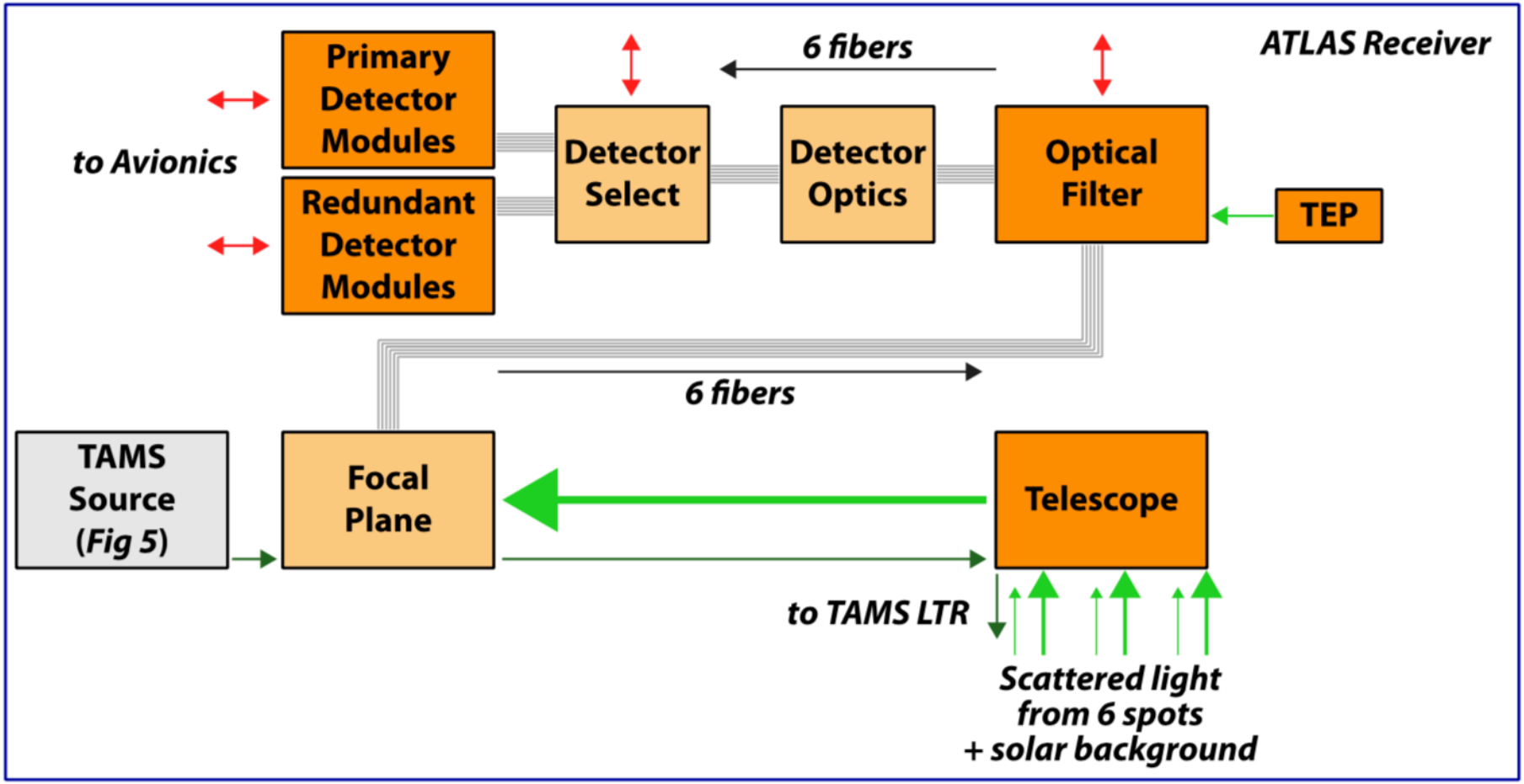


3 km spacing between pairs provides spatial coverage
90 m pair spacing for ***slope determination*** (2° yaw)
high-energy beams (4x) for better performance over low-reflectivity targets.

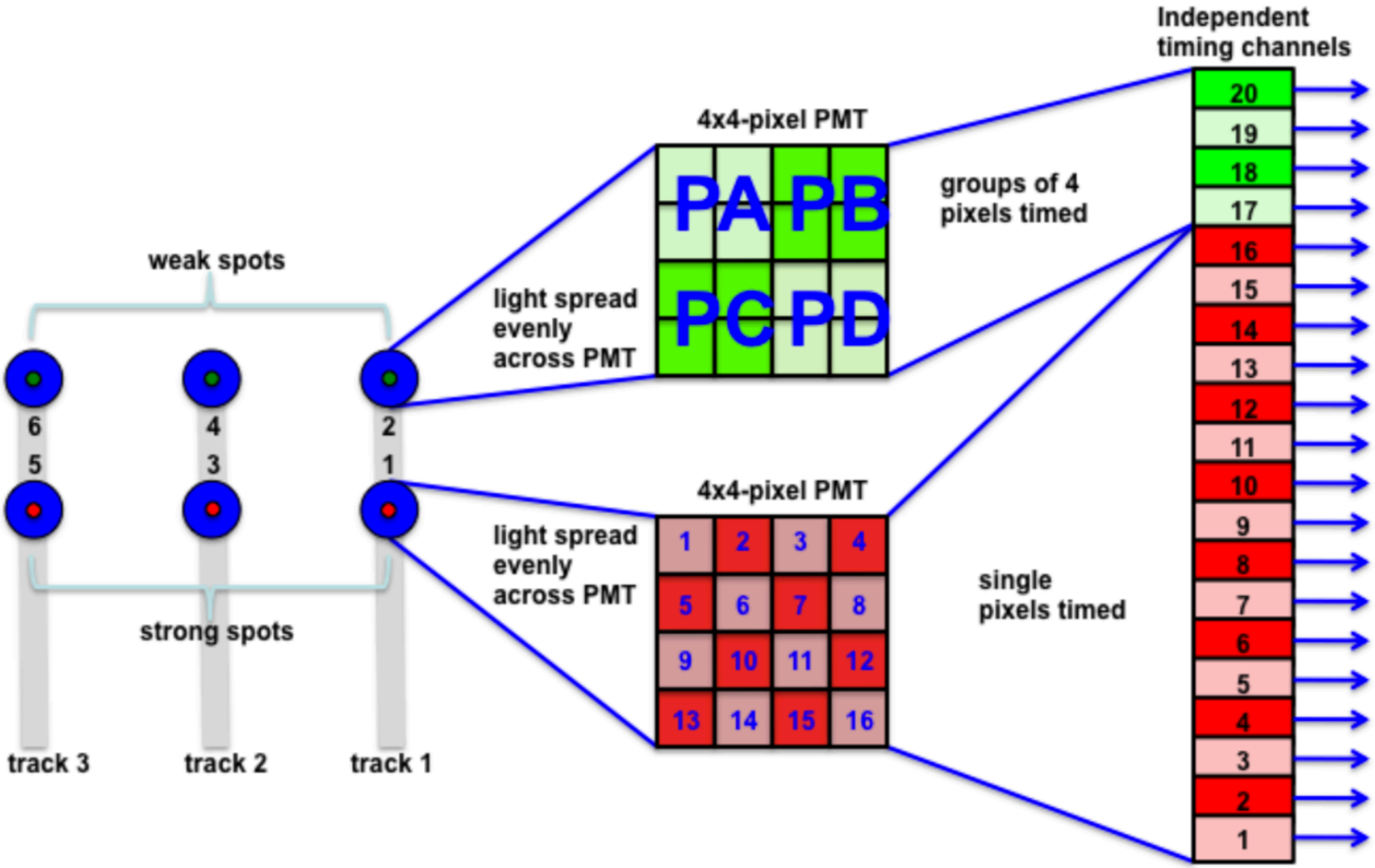
ATLAS Transmitter



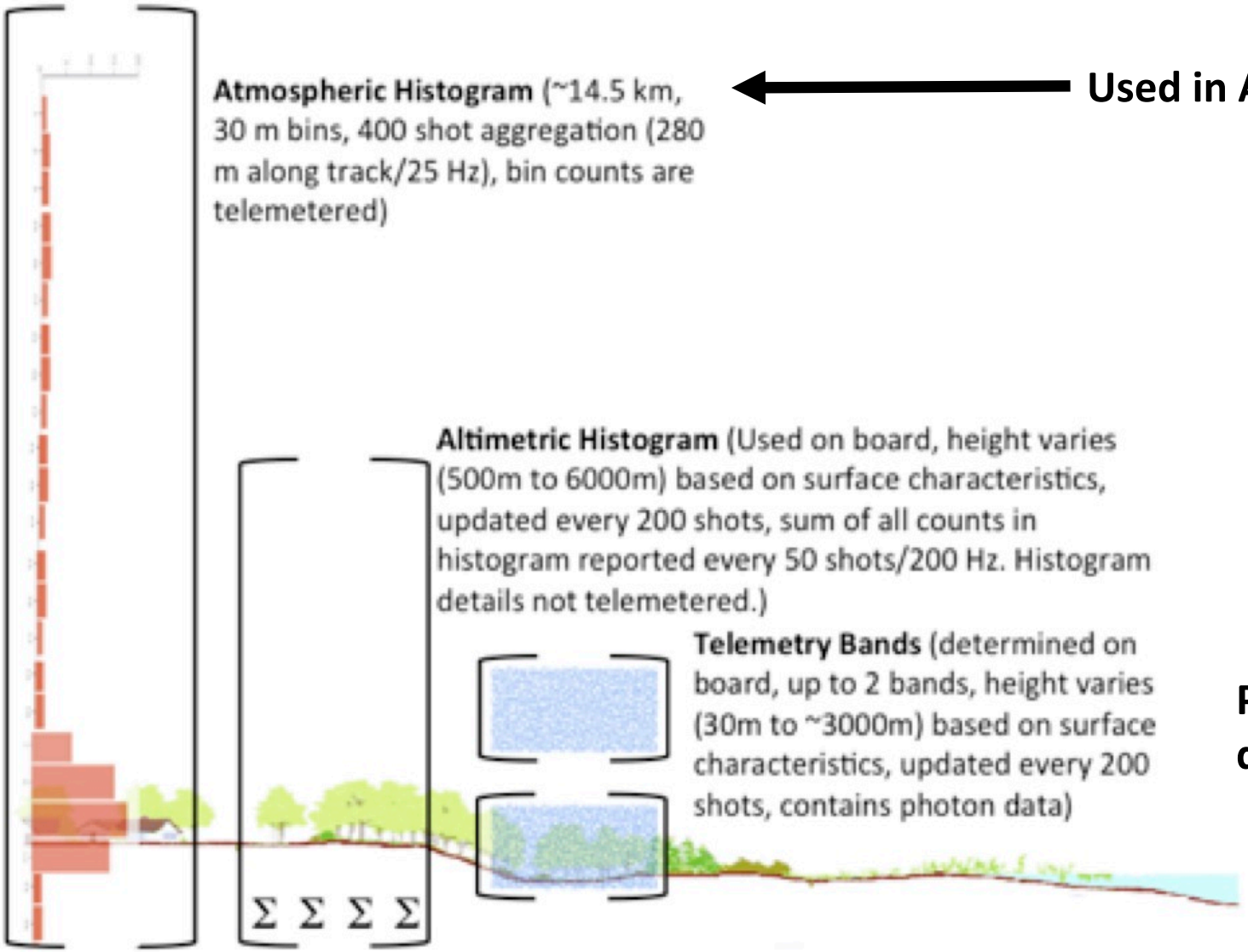
ATLAS Receiver



ATLAS Timing



ATLAS Data Selection



ATLAS Instrument Details

Transmitter	
wavelength (nanometers)	532.272
footprint diameter (m; microradians)	~12; <35 at 85% ee
pulsewidth (nanoseconds, FWHM)	< 1.5
pulse energy (millijoules)	0.2 to 1.2
optical throughput efficiency	73%
number of beams; energy ratio (weak:strong)	6; 4:1
nominal strong beam (microjoules)	200 (adjustable)
nominal weak beam (microjoules)	50 (adjustable)

ATLAS Instrument Details

Receiver	
telescope diameter (m)	0.8
receiver field of view (m, microradians)	42.5, 83.3
optical filter bandpass (picometers)	30
optical throughput efficiency	42%
detector efficiency	15%
single photon precision (m, picoseconds)	0.23, 775
max signal photons per shot, strong	10
max signal photons per shot, weak	2.5

Low-Level Products

Data from S/C downlinked ~7x / day

Ground stations in Svalbard and Poker Flat, AK

NASA networks brings data to GSFC

~450 Gbit / day

ATL01

Unpacks Data / conversion from binary

Stored in HDF5 format

ATL02

Applies conversions to yield times, temperatures, voltages

Photon time of flight calculated

Organized by beam

All other S/C data (star trackers, GPS) passed through

ATL03: Geolocated Photons

Position of observatory in space:

Precision Orbit Determination – NASA GSFC
Based on Ruag GPS receivers
verified with satellite laser ranging (orbit known to < 3 cm radial)

Pointing vectors for ATLAS laser beams:

Precision Pointing Determination – U of Texas Applied Res. Lab
Based on Sodern Star Trackers and Laser Reference System
verified with ATL03 photon data

Photon time of flight + POD + PPD → Photon ground bounce point

One photon precisely geolocated every 20m, others geolocated WRT

Along-track geolocation segment / reference photons

ATL03: Geolocated Photons

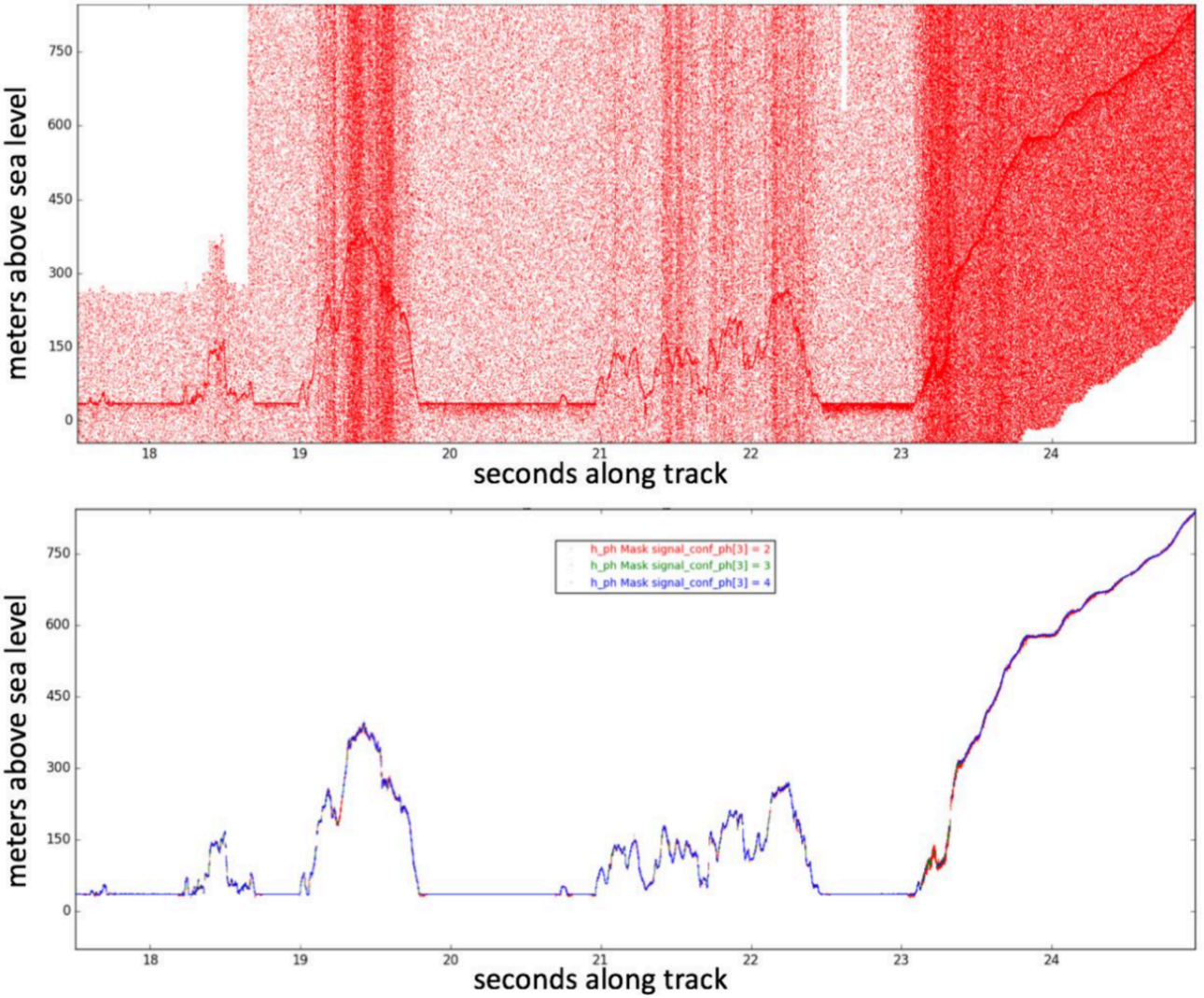
Classify Photons

Reduce data volume higher-level products have to deal with

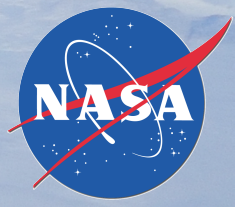
Histogram-based approach

Parameters are surface specific

Likely signal photons w/ high, medium or low confidence

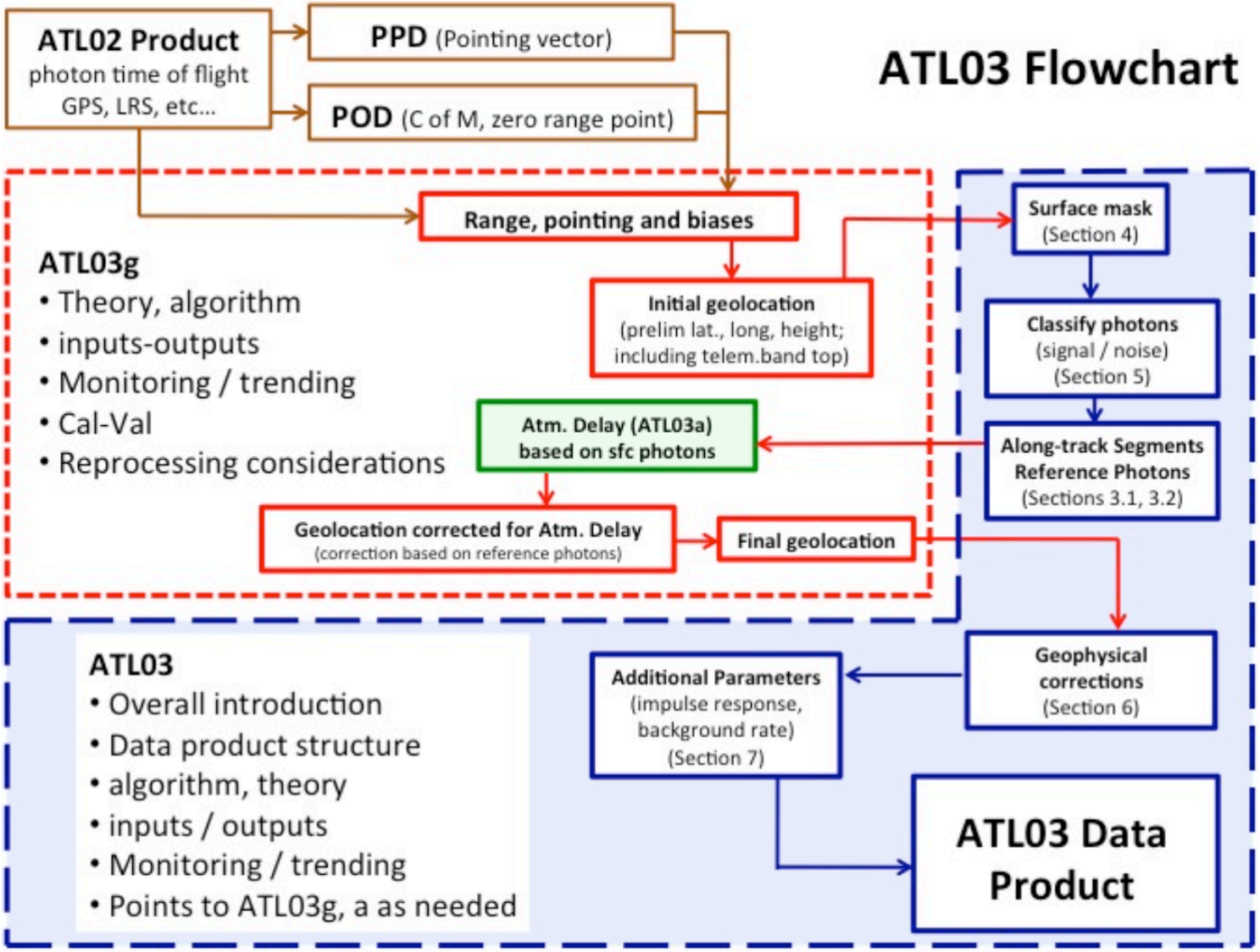


ATL03: Geophysical Corrections

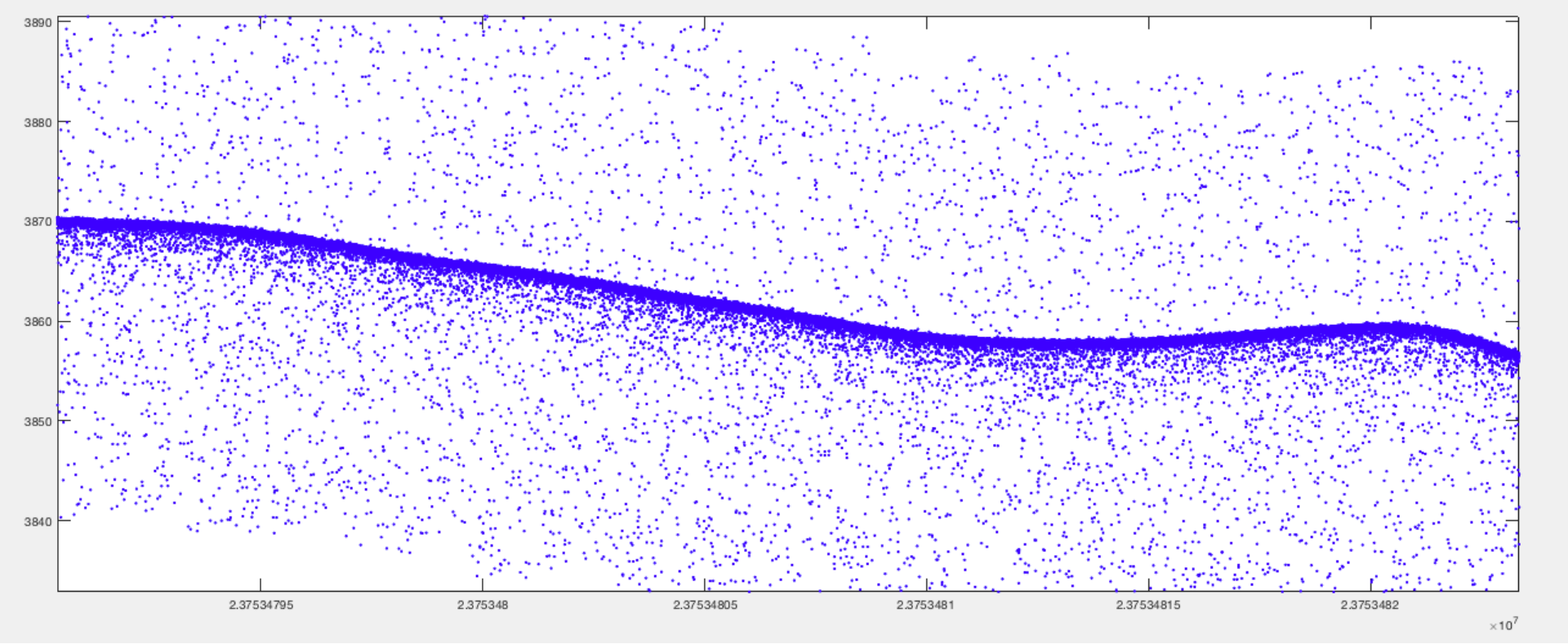


Model Type	Input Params	Output Params	Applied?	Processing/Source Candidates
Ocean Tides	lat, lon, time	ocean height correction	R	GOT4.8 – in-house support
Met Data	lat, lon, time	surface and column temperature, pressure	R	NASA GMAO GEOS5 FP-IT
IB/DAC	lat, lon, time	ocean height correction	R	MOG2D (AVISO)
Ocean Loading	lat, lon, time	ocean height correction	C	GOT4.8 – supplemental files
Solid Earth Pole Tide	lat, lon, time	solid earth deformation	C	IERS Conventions (2010)
Ocean Pole Tide	lat, lon, time	ocean height correction	C	IERS Conventions (2010)
Solid Earth Tides	lat, lon, time	solid earth deformation	C	IERS Conventions (2010)
Geoid	lat, lon	reference surface	R	EGM2008, mean tide system
Geocenter Motion	time	Cartesian shift of tracking stations	N	Via SLR/GPS estimation, applied in POD
Total Column Atmospheric correction	lat, lon, time	range correction	C	Recommendation by Luthcke & Petrov, cf. ATBD ATL03a

ATL03: Geolocated Photons

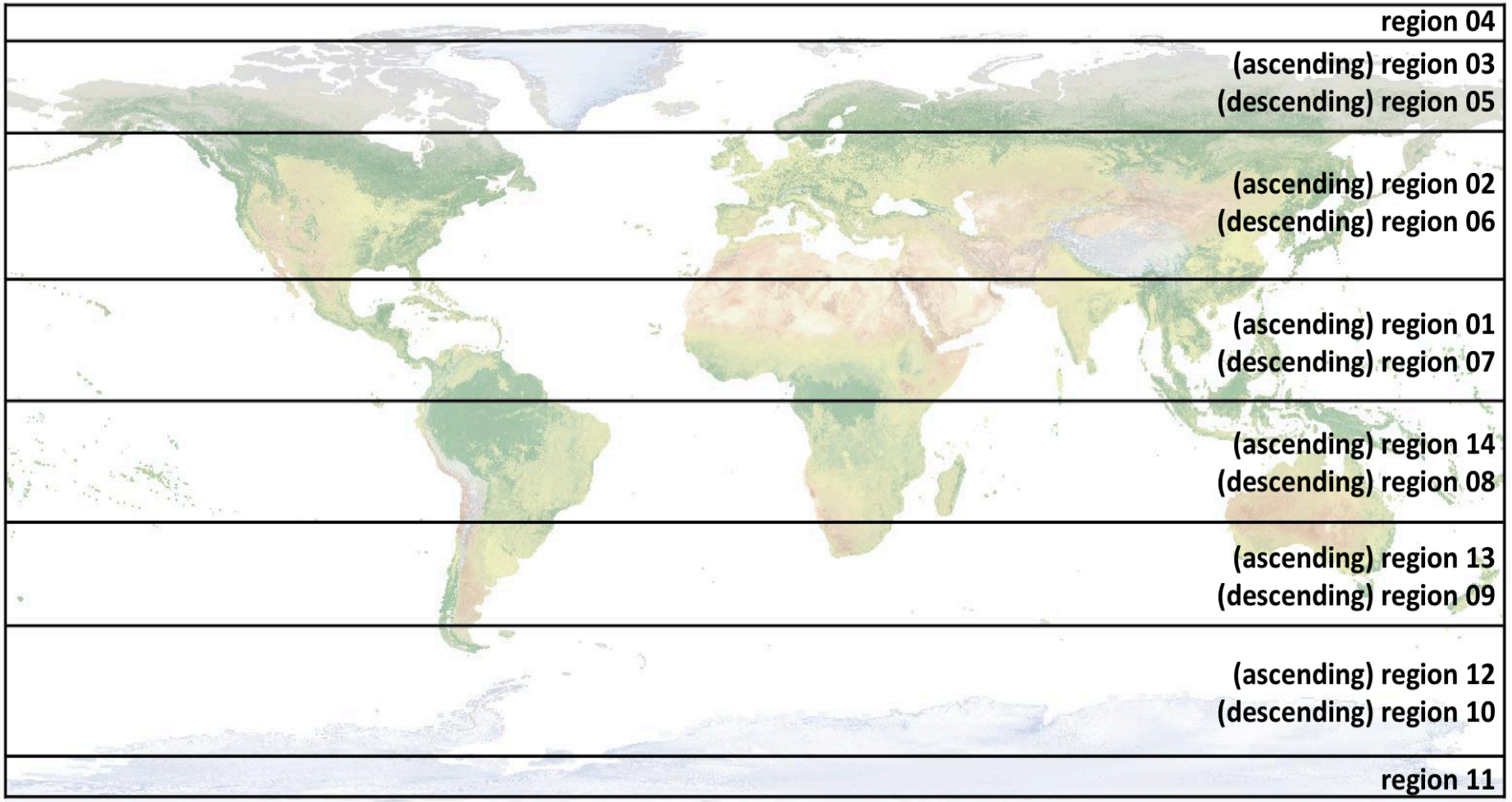


First ATL03: 3 October 2018



Latitude, longitude, height for every photon (WGS-84 ellipsoid / ITRF-2014)

ICESat-2 Regions



Orbit Coverage

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NASA

500 km altitude

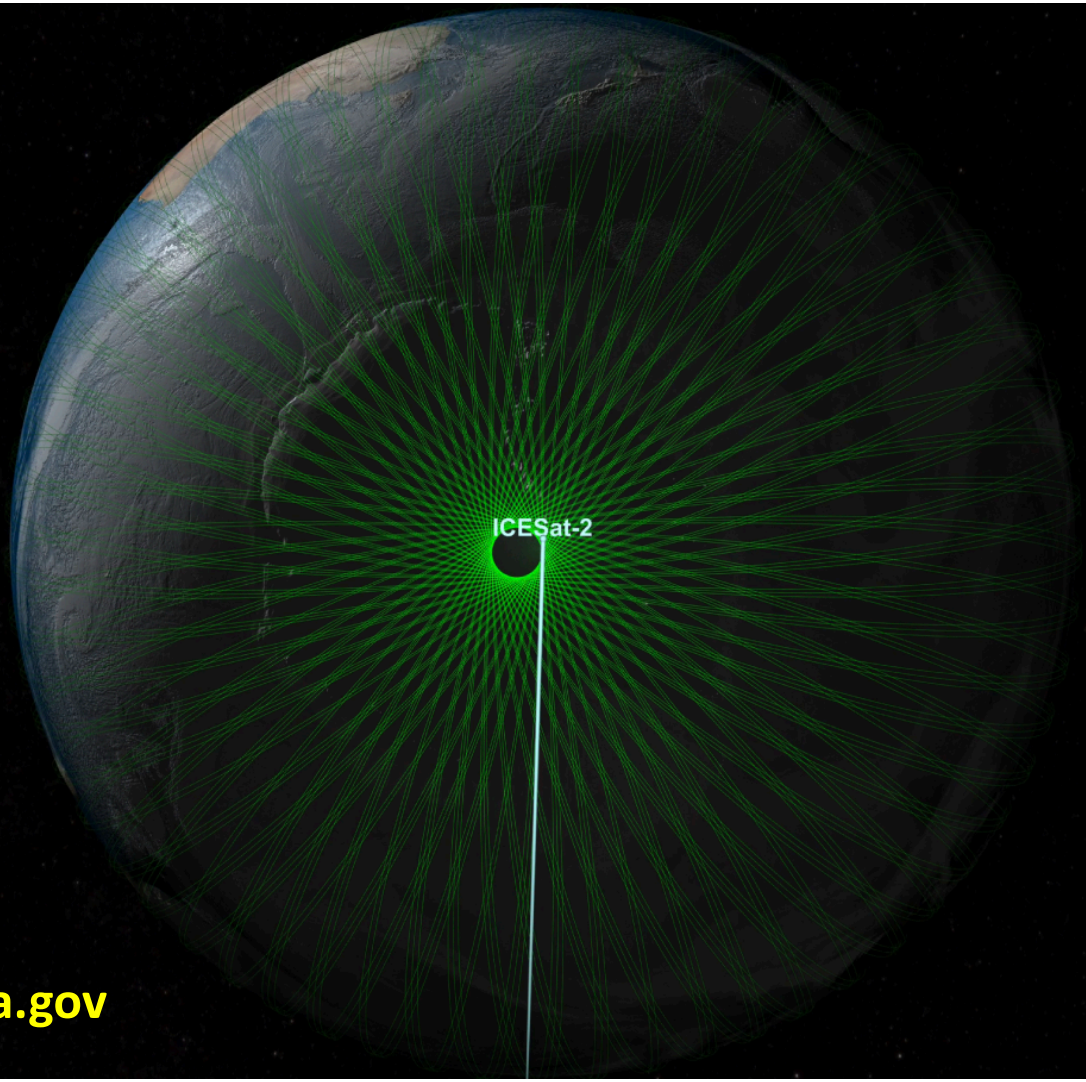
88S to 88N

15 revs/day

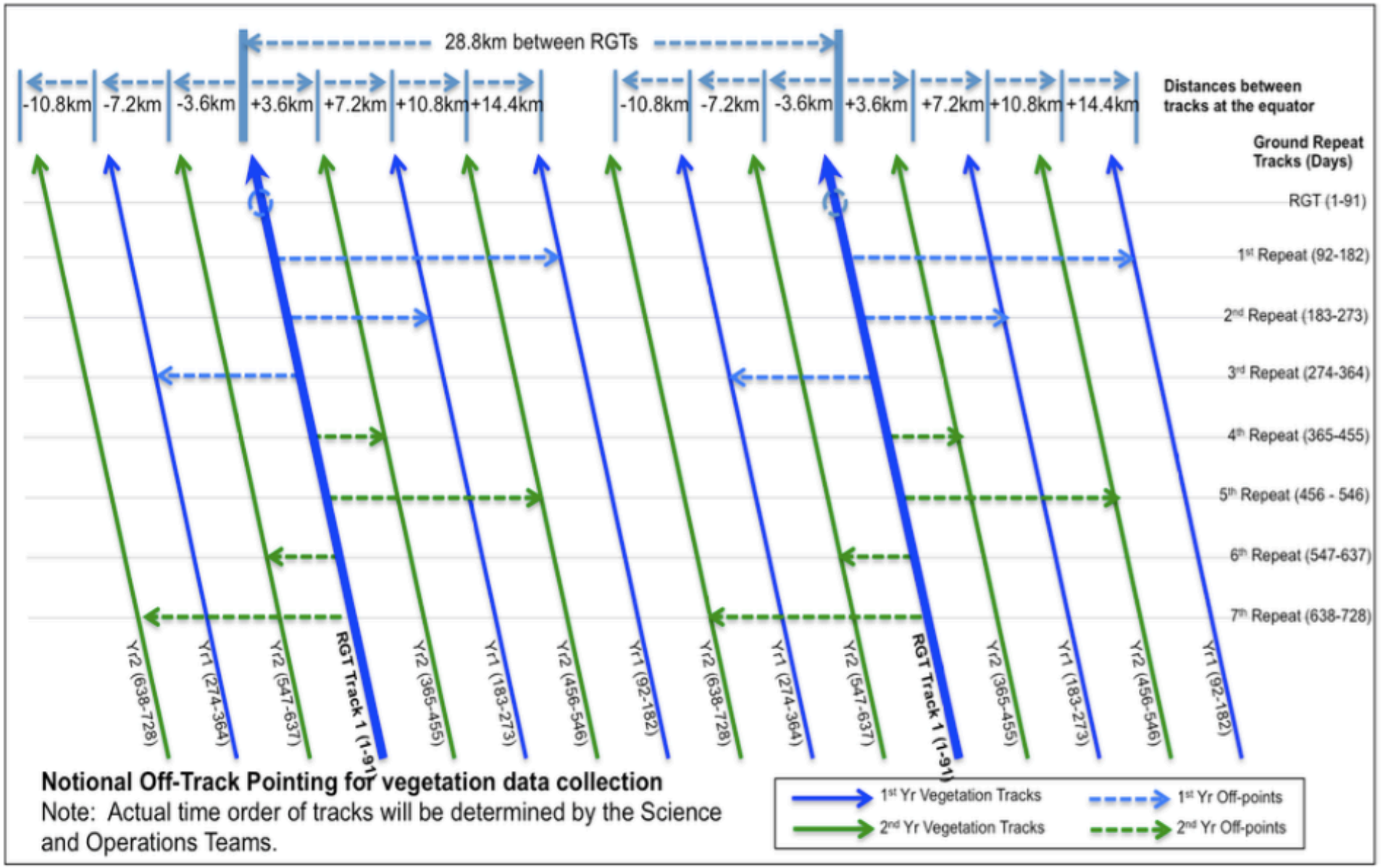
1387 tracks

91-day revisit

Ground tracks at
icesat-2.gsfc.nasa.gov



Off-pointing in Mid-Latitudes



Notional Off-Track Pointing for vegetation data collection

Note: Actual time order of tracks will be determined by the Science and Operations Teams.

Orbit and Cross Overs

ICESat-2's orbit:

- 91-day exact repeat orbit with monthly sub-cycle
- Inclination: 92º (88º north and south)
- Altitude: ~500 km

Driven by:

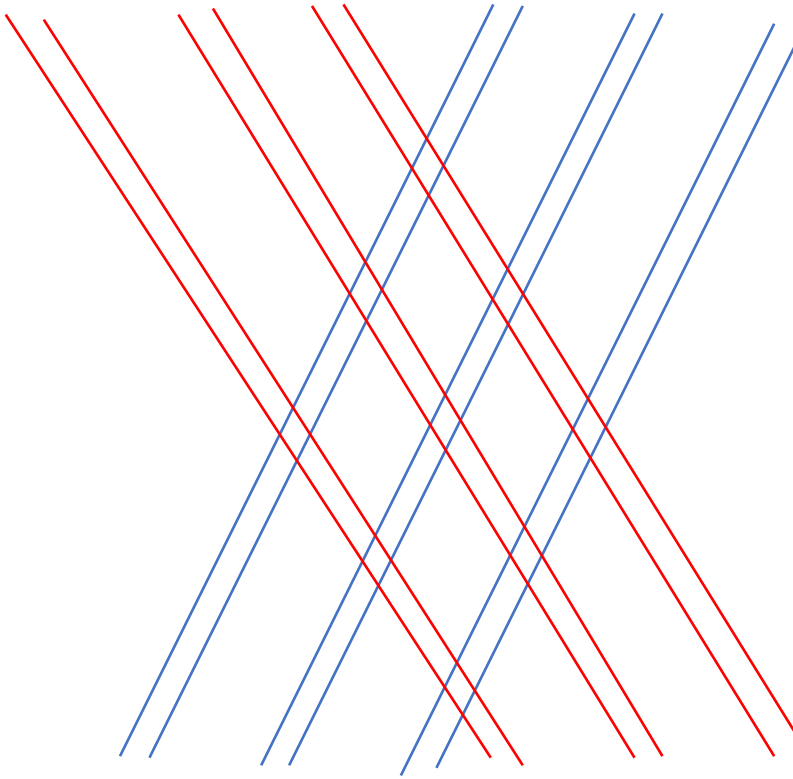
Seasonal requirement for ice sheet changes
Monthly requirement for sea ice

Compromise between high-latitude coverage and cross-over distribution

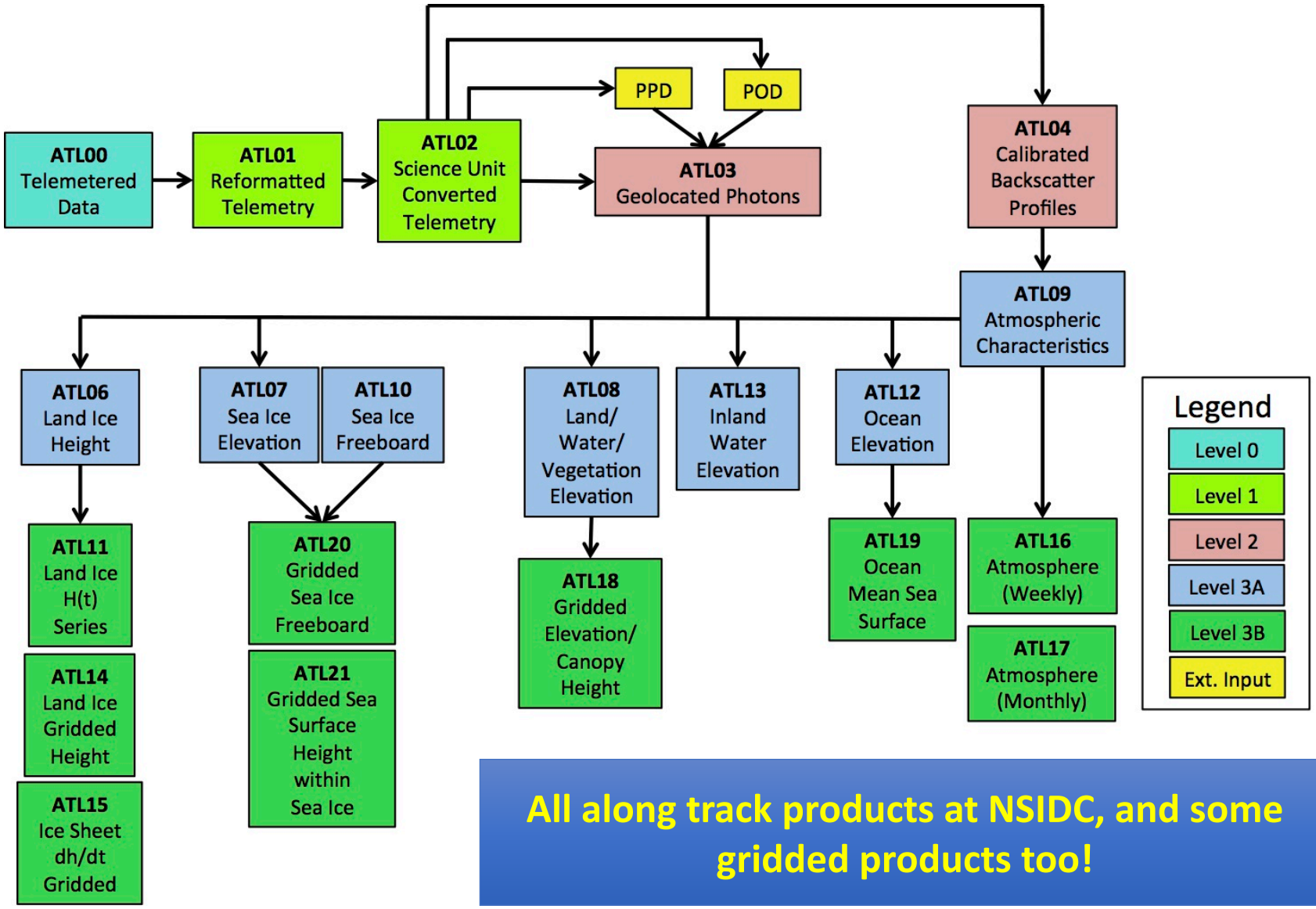
Cross-Overs:

With 6 beams, each ground track cross-over generates 36 individual crossings. … or 9 slope-corrected crossings

Primary method of monitoring ATLAS range bias and data consistency

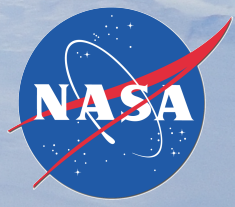


ICESat-2 Data Products



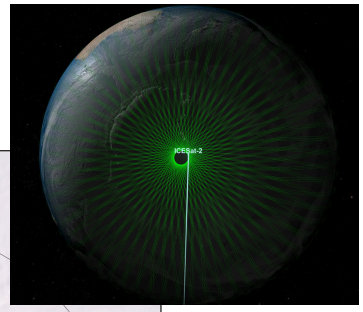
All along track products at NSIDC, and some gridded products too!

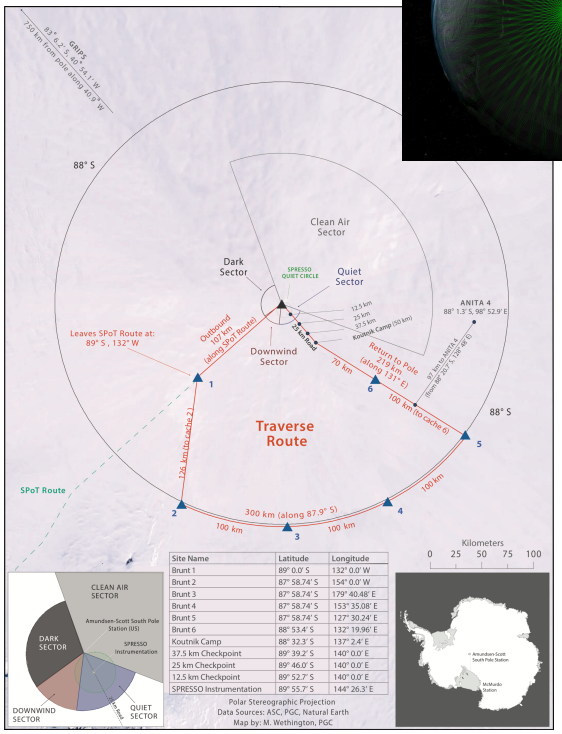
Data Product Leads



ATBD	Lead	Affiliation	ATLAS Science Data Products	Description
Precision Pointing Determination (PPD)	Sungkoo Bae	UTCSR	ancillary data	Precise laser pointing solutions input to all level 2 and higher level products
Precision Orbit Determination (POD)	Scott Luthcke	GSFC	ancillary data	Precise orbit solutions input to all level 2 and higher level products
Level 1A	John DiMarzio	SGT/GSFC	ATL01	Conversion and reformatting of Level 0 data
Level 1B	Tony Martino	GSFC	ATL02	Apply necessary corrections from housekeeping data, e.g. calibrated ranges
Level 2A	Tom Neumann	GSFC	ATL03	combine elevation corrections, geolocation information, laser spot location (which requires preliminary surface finding) with L1B product; also will produce histograms
Ice Sheet	Ben Smith	UW	ATL06, 11, 14, 15	Define ice sheet products and parameters
Sea Ice	Ron Kwok	JPL	ATL07, 10, 20, 21	Define sea ice products and parameters
Land	Amy Neuenschwander	UT-ARL	ATL08, 18	Define land and vegetation products and parameters
Ocean	James Morison	UW	ATL12, 19	Define ocean products and parameters
Atmosphere	Steve Palm	SSAI/GSFC	ATL04, 09, 16, 17	Define atmosphere products and parameters and the calibrated backscatter
Inland Water and Snow	Mike Jasinski	GSFC	ATL13	Surface height and slope of inland water bodies

Calibration Activities





ATLAS Spot	ATL03 bias ±precision (cm)	ATL06 bias ±precision (cm)
1	-0.8 ±13.1 (*N*=659)	-2.8 ±8.9 (*N*=661)
2	+2.0 ±9.4 (*N*=551)	-1.5 ±8.8 (*N*=645)
3	+4.5 ±8.9 (*N*=1019)	+1.7 ±7.7 (*N*=1018)
4	+3.6 ±8.4 (*N*=927)	+0.6 ±7.9 (*N*=1009)
5	+5.1 ±10.3 (*N*=865)	+2.3 ±7.6 (*N*=863)
6	+6.1 ±10.9 (*N*=742)	+2.7 ±8.1 (*N*=805)

Brunt, Neumann, and Smith (Geophysical Research Letters, 2019)

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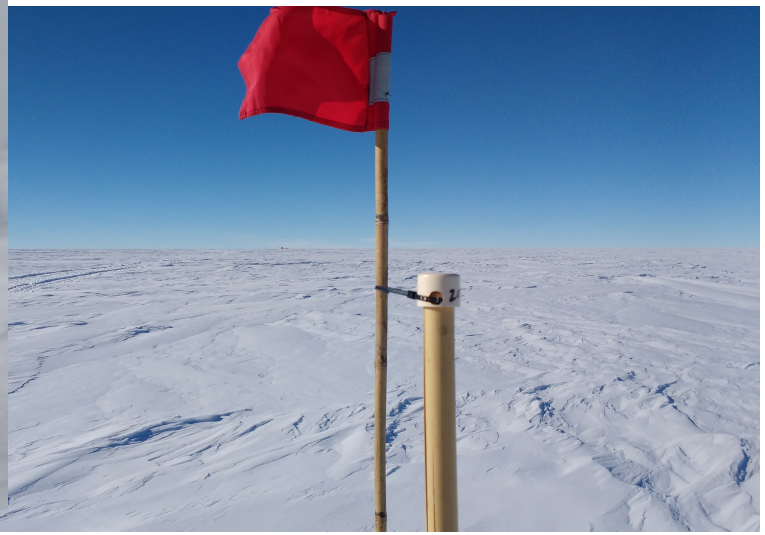
Calibration Activities

NASA

Calibration Activities



IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING

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

Lori A. Magruder, and Kelly M. Brunt

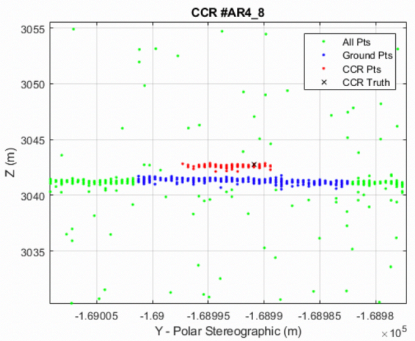


Figure 15. ATL03 geolocation signal photons for track 1111 at 88S. The green points are signal, the blue points are signal determined to be from the CCRs and the red x's are the actual CCR positions. The lower plot is the CCR return signature; the blue data are the ground signal and the red data are from the CCR based on relative location and height above the surface.

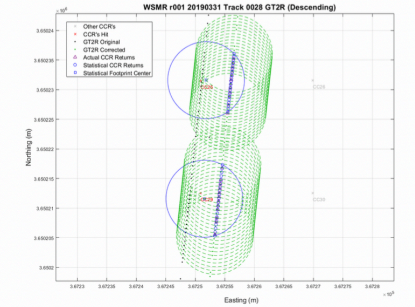


Fig. 14. Analysis results for CCR geolocation accuracy recovery from 28 September 2019. The black points are the ATL03 reported photon geolocations and the green are the true locations using the CCR positions and the signal signature chord lengths.

ICESat-2 footprint: 12.7 m
(CBE, pre-launch: 17 m)

ICESat-2 Data are Publicly Available

National Snow and Ice Data Center (NSIDC DAAC)

Data Products:

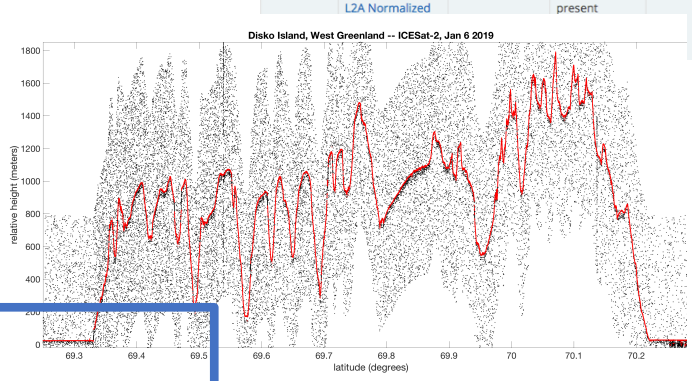
- Geolocated Photons
- Land Ice Elevation
- Sea Ice Elevation and Freeboard
- Land Elevation
- Atmospheric Backscatter
- Ocean Surface Height
- Inland Water Elevation

Overview
ICESat-2 Data Sets
Product Descriptions
Level-1
Level-2
Level-3A
Level-3B
Tools
Knowledge Base
ICESat/GLAS Data
IceBridge Data

ICESat-2 Data Sets at NSIDC

The following table lists the ICESat-2 data sets that are currently available at the NASA NSIDC DAAC.

ID	Title	Spatial Coverage	Temporal Coverage	Spatial Resolution	Temporal Resolution	Parameter(s)
ATL02	ATLAS/ICESat-2 L1B Converted Telemetry Data, Version 1	GLOBAL	2018/10/13 to present	Not applicable	Not applicable	Engineering Telemetry Ancillary Data
ATL03	ATLAS/ICESat-2 L2A Global Geolocated Photon Data, Version 1	GLOBAL	2018/10/13 to present	70 cm	91 day	TERRAIN ELEVATION
ATL04	ATLAS/ICESat-2 L2A Normalized	GLOBAL	2018/10/13 to present	280 m	91 day	Lidar Backscatter



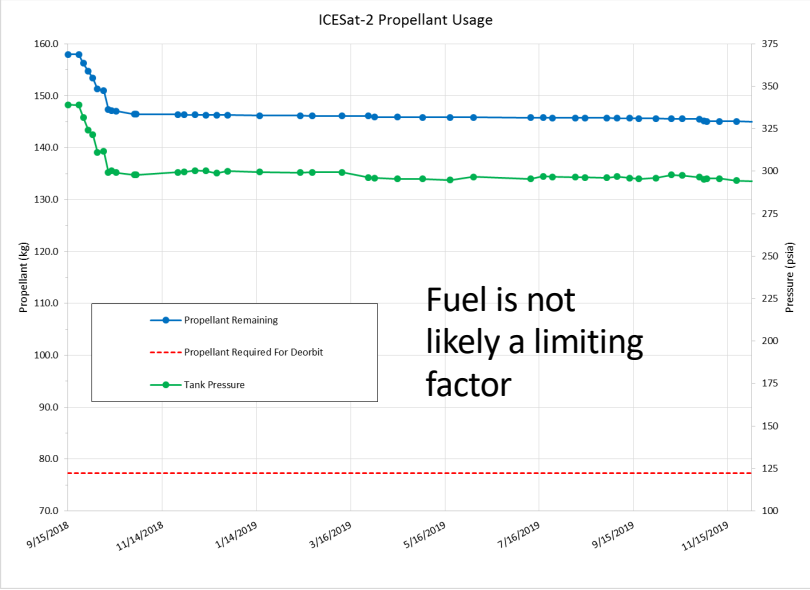
Rugged topography in Greenland

1955 unique data users to date
From 82 countries
5,289,808 files served from 28 May 2019 – 1 June 2020

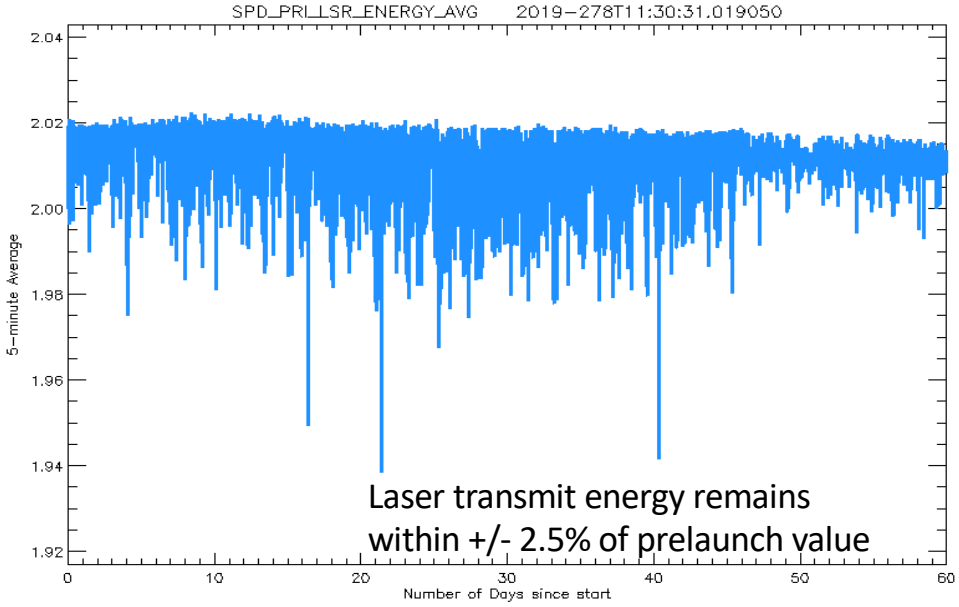
ATLAS Remains Nominal

One safehold event (26 Jun – 9 July)
And two ATLAS software upsets (7 Nov and 26 Dec 2019)

Otherwise, observatory remains nominal.



Fuel is not likely a limiting factor



Laser transmit energy remains within +/- 2.5% of prelaunch value

Laser lasing at energy level 4 …. of 11
Steps spaced by ~10% between 0.2 and 1.2 mj

ICESat-2: Measuring the Height of Earth One Photon At a Time

ICESat-2 is well on it's way to nominal science data production.

After 600 Billion shots (as of 1 June) ATLAS is stable and healthy.

Release 003 data from 14 October 2018 to 6 April 2020 available. More on the way!