ATM

The Airborne Topographic Mapper Instrument Suite

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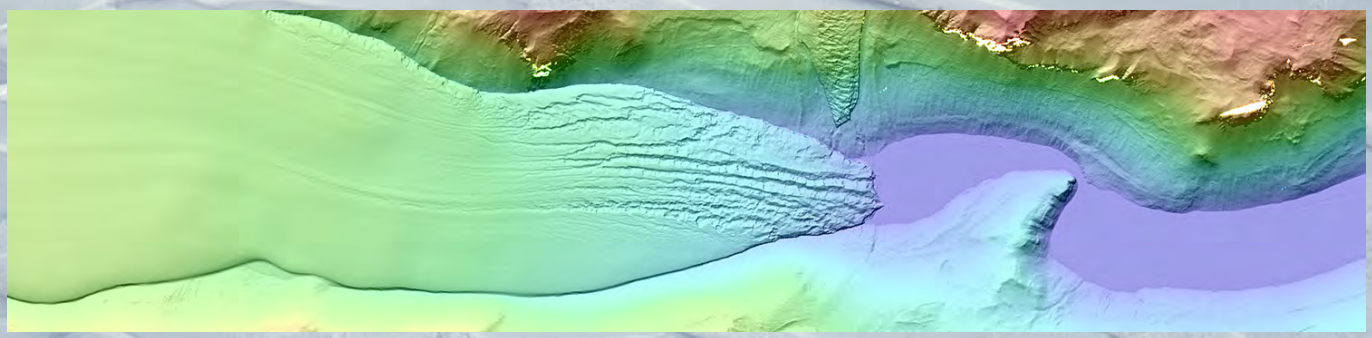
The Airborne Topographic Mapper Instrument Suite

- The ATM instrument suite is a **versatile package of airborne science instruments** that **can be tailored** to many different science applications and platform configurations.
- The ATM instrument suite has collected **geodetic-quality topographic measurements** from a wide variety of platforms, including the NASA P-3, the Chilean Navy P-3, the US Navy P-3, NOAA P-3, the NASA DC-8, the NCAR C-130, the NASA C-130, the two NASA HU-25Cs, and a half-dozen Twin Otter aircraft.
- The ATM instrument suite has been **adapted to various platforms**, and typically operates at altitudes from 1,500 ft/450 m above ground level (AGL) (preferred) up to 35,000 ft/10,000 meters.
- Part of the instrument suite is **ATM's precision aircraft guidance system** that can precisely steer the aircraft within 3 meters of the desired path to obtain overlapping data for change detection and/or precise spacecraft underflights.

- ATM operates **multiple LiDAR systems** which can be **custom modified to specific science customer requirements (coastline mapping, streambeds, ice, bathymetry, wave mapping**, etc.)
- High-rate (10,000 Hz), narrow (1.3 ns), small footprint (~1 m) laser pulses with ability to fly two LiDAR systems on many airborne platforms which allows dense surface coverage with different customizable scan widths.
- High-bandwidth detectors and **multi-trigger waveform recording** for **precision elevations** and **detection of multiple surfaces**, bathymetry and now measurement of laser scattering within snow and ice surfaces.
- **Simultaneous 532 nm and 1064 nm co-located laser pulses** enables differentiation between surface penetration for water, ice and snow and possible other surfaces.
- **Strong record of mission success** (750 polar missions flown) and **data archive delivery** (fast processing product within days, final data HDF5 delivery for entire deployment in 6 months).
- **Ancillary remote sensing instrumentation:** thermal imaging camera, hyperspectral imager, and georeferenced photo images provide self-contained mission support.



ATM high-resolution digital elevation model (DEM) of Taylor Glacier and Lake Bonney in the Dry Valleys of the Transantarctic Mountains, Antarctica.

The Airborne Topographic Mapper Instrument Suite

ATM Capabilities

- ATM operates **multiple LiDAR systems** which can be **customized to specific science customer requirements (coastline mapping, streambeds, ice, bathymetry, wave mapping, etc.)**

- **High-rate** (10,000 Hz), **narrow** (1.3 ns), **small footprint** (~1 m) laser pulses. The ability to fly two LiDAR systems on many airborne platforms allows dense surface coverage with different customizable scan widths.

- High-bandwidth detectors and **multi-trigger waveform recording** for **accurate elevations and detection of multiple surfaces**, bathymetry and now measurement of **laser scattering** within snow and ice surfaces.

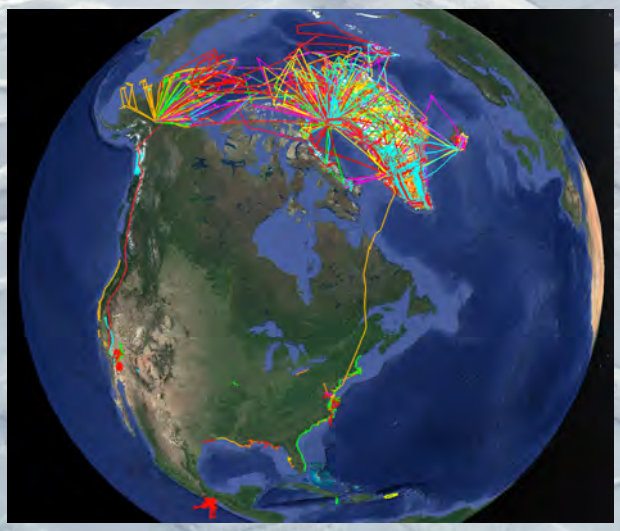
- **Simultaneous 532 nm and 1064 nm co-located laser pulses** enables differentiation between surface penetration for water, ice and snow and other surfaces.

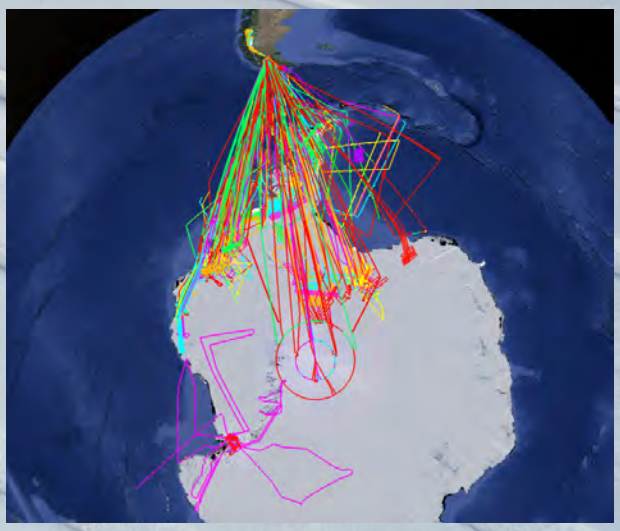
- **Proven long DGPS baseline trajectories** via custom ATM GPS multi-base station processing and atmospheric corrections enable precise ATM elevation maps in remote regions.

- **Custom ATM aircraft navigation capabilities** precisely position the ATM swath over required target locations. Real time corrections for sea ice drift, coordination with satellite overpasses.

- **Strong record of mission success** (750 polar missions flown) and **data archive delivery** (fast processing product within days, final data HDF5 delivery for entire deployment in 6 months).

- **Ancillary remote sensing instrumentation:** thermal imaging camera, hyperspectral imager, and georeferenced photo images provide self-contained mission support.





ATM Survey Flights 1993 - 2019

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The main components of the ATM instrument suite are two conically-scanning laser altimeters that independently measure the surface topography of the swath beneath the aircraft at a 15° and 2.5° off-nadir angles respectively. ATM's current instrument suite consists of:

Instrument	Scan angle	Wavelength [nm]	PRF (Hz)	Pulse Width [ns]	Swath width at 450 m AGL	Footprint size at 450 m AGL
ATM 6d-T7	2.5°	532	10,000	1.3	40 m	0.64 m
ATM 6c-T7	2.5°	1064	10,000	1.3	40 m	0.91 m
ATM 6a-T6	15°	532	10,000	1.3	245 m	0.64 m

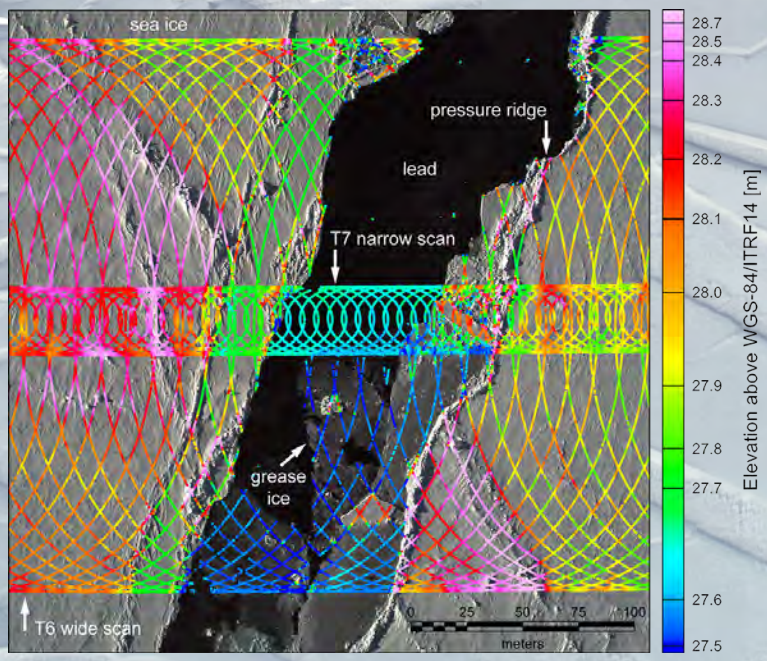
The ATM-T7 scanner is a **dual-color laser with co-located footprints** on the surface.

Auxiliary Instrument Suite

Natural color digital imagery: Continuous Airborne Mapping By Optical Translator (CAMBOT): The CAMBOT camera is a Prosilica GT APS-H camera capturing 4896 × 3264 pixels with a 28 mm ZEISS lens. At 450 m flight elevation above ground, the camera images a 280 meter-wide swath beneath the aircraft with a pixel resolution of 7 cm.

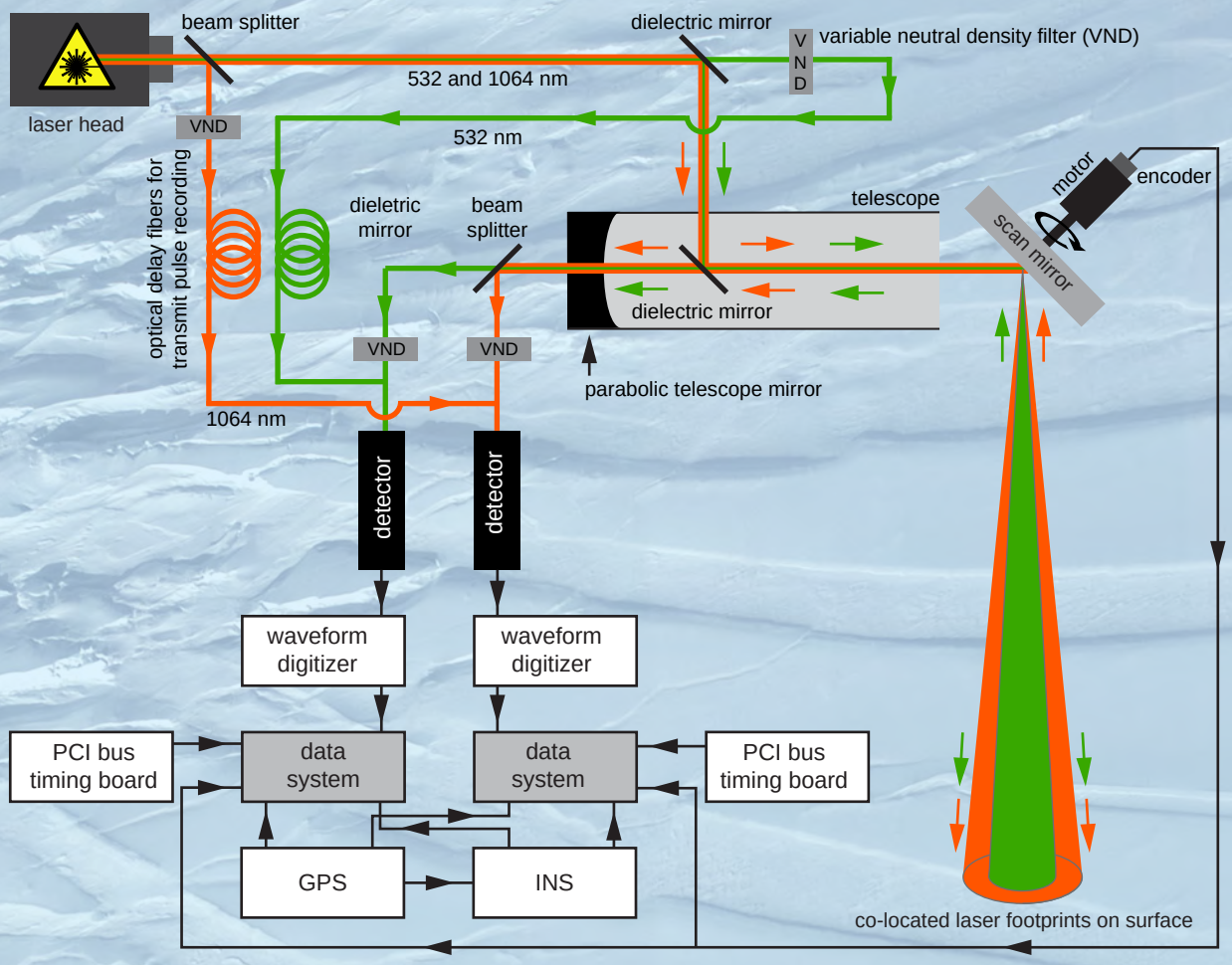
FLIR A655sc Thermal Imaging Camera: The camera's microbolometer records 16-bit 640 × 480 pixel images with a temperature resolution of < 30 mK. The thermal images slightly exceed the area the ATM wide scanner images and have a pixel size of roughly 0.6 × 0.6 meters at 450 m AGL.

Headwall Hyperspectral Imager: The Headwall Photonics HYPERSPEC® is a push-broom sensor with a wavenumber range of 400 – 2500 nm and dual VNIR/SWIR sensors with co-aligned pixels. The sensors have 270 (VNIR) & 267 (SWIR) spectral pixels with 640 pixels across the swath with 12 (VNIR) and 16 bit (SWIR) resolution.



Left: ATM narrow and wide angle scan laser data over sea ice in the Arctic Ocean north of Greenland. Note the higher return rate of the narrow scan laser (T6) over the sea ice lead (dark areas) that enables sea surface height determination for precise freeboard estimates, and the denser shot spacing compared to the wide angle scanner (T7). Colors show elevation in meters above the WGS-84 reference ellipsoid. Background image is a geolocated, orthorectifiec natural-color image from ATM's CAMBOT camera.

ATM's dual-color co-located T7 LiDAR

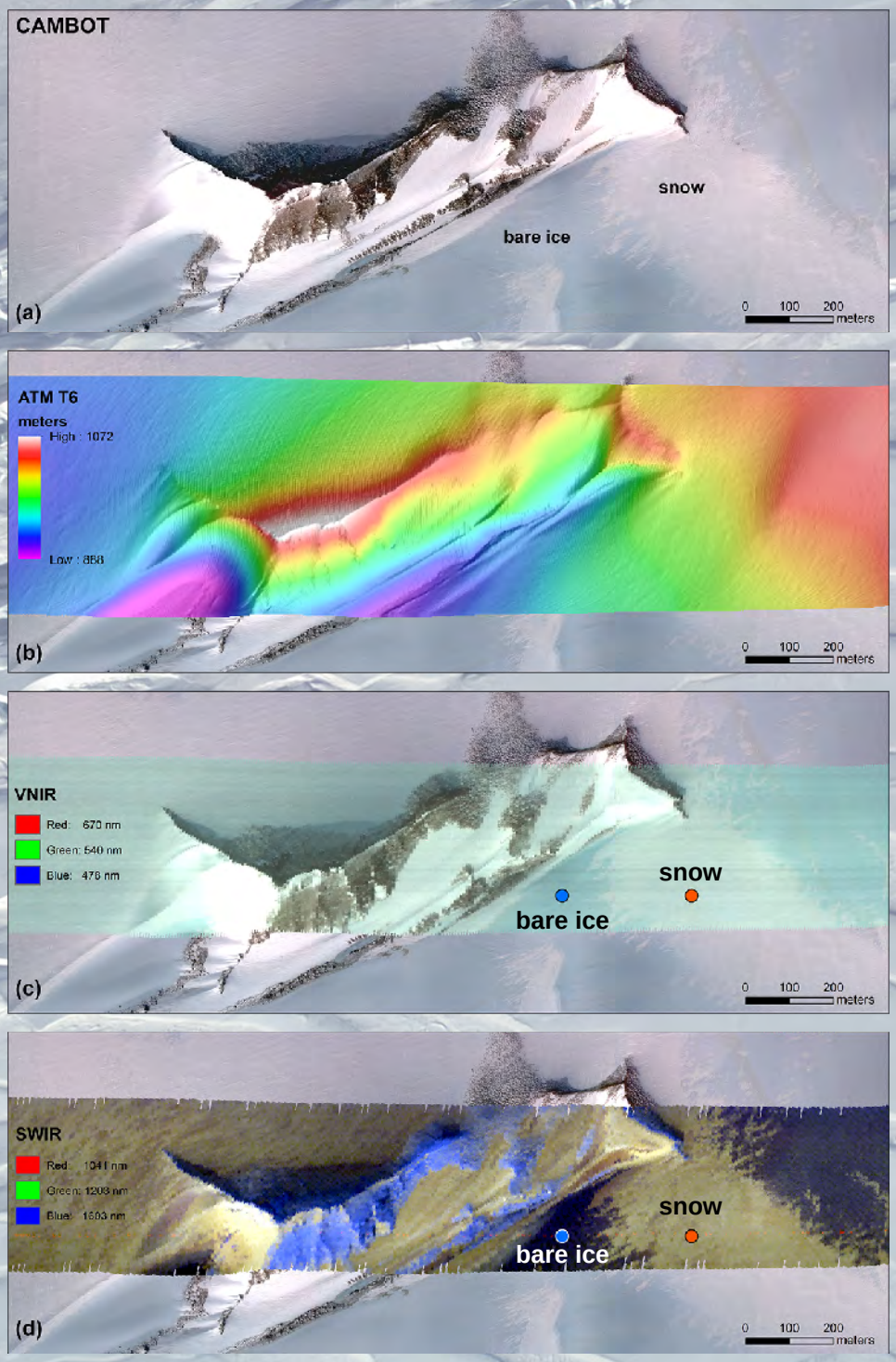


Unlike commercially available multi-color LiDAR systems, ATM's dual-color T7 LiDAR has truly colocated 532 and 1064 nm footprints.

Responding to concerns in the ICESat-2 Science Definition Team and recommendations from the OIB mid-term review panel ATM T7 was designed to use a separate infrared (IR) optical channel to make parallel and separate IR transmit and receive waveform measurements from the same laser pulse. The T7 optical system uses a common IR and green optical path on the transmit side, and common IR and green optical flat and telescope optics on the receive path through the system, directing the green to a PMT detector and the IR to an PIN Photodetector (left).

These paired green and IR return waveform measurements can be deconvolved (using the transmitted pulse waveforms) and compared over various surfaces to measure the interaction of lidar pulses with those surfaces. **We are not aware of any commercially available or other dual-color LiDARs that have truly colocated 532 and 1064 nm footprints as ATM's T7. This ATM research capability does not exist elsewhere.**

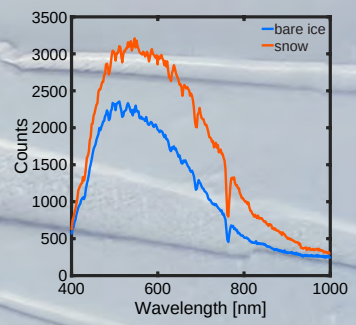
ATM's Auxiliary Instrument Suite



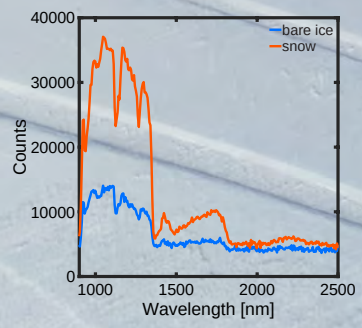
CAMBOT visible imagery

DEM from T6 laser scanner

VNIR spectra



SWIR spectra



Pioneers Escarpment, Antarctica. Example of how ATM's multi-sensor suite can be used for research applications. The visible imagery (a) allows to distinguish areas with bare ice from snow covered areas. The waveforms from the lidar (b) can be used to derive snow grain size (not shown) which can be supported by spectra from hyperspectral data (c, d).

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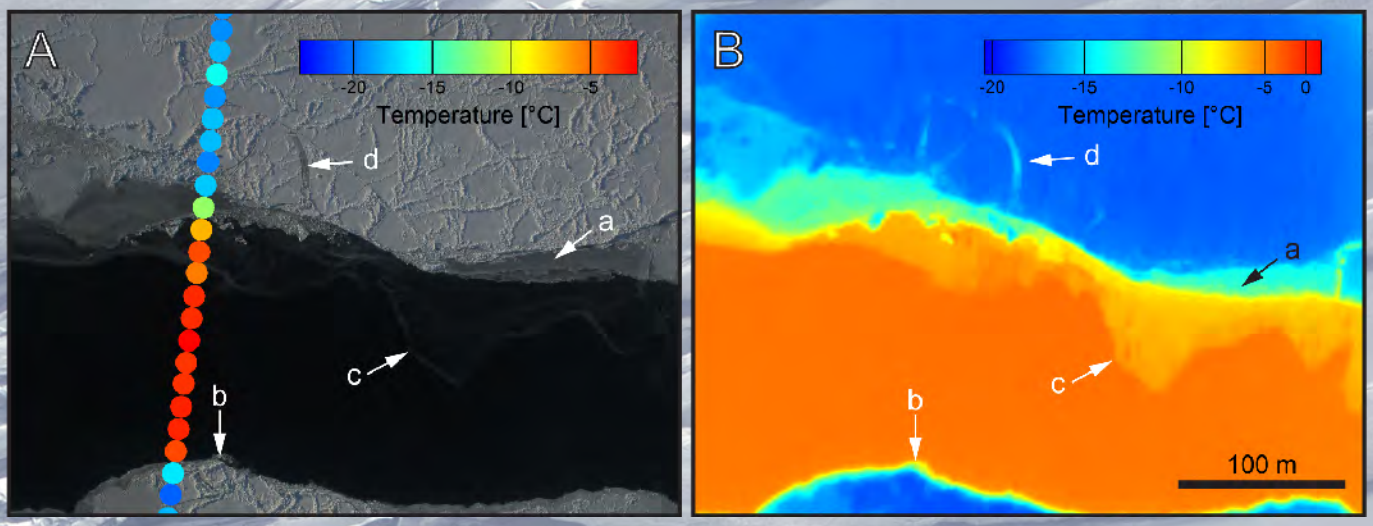
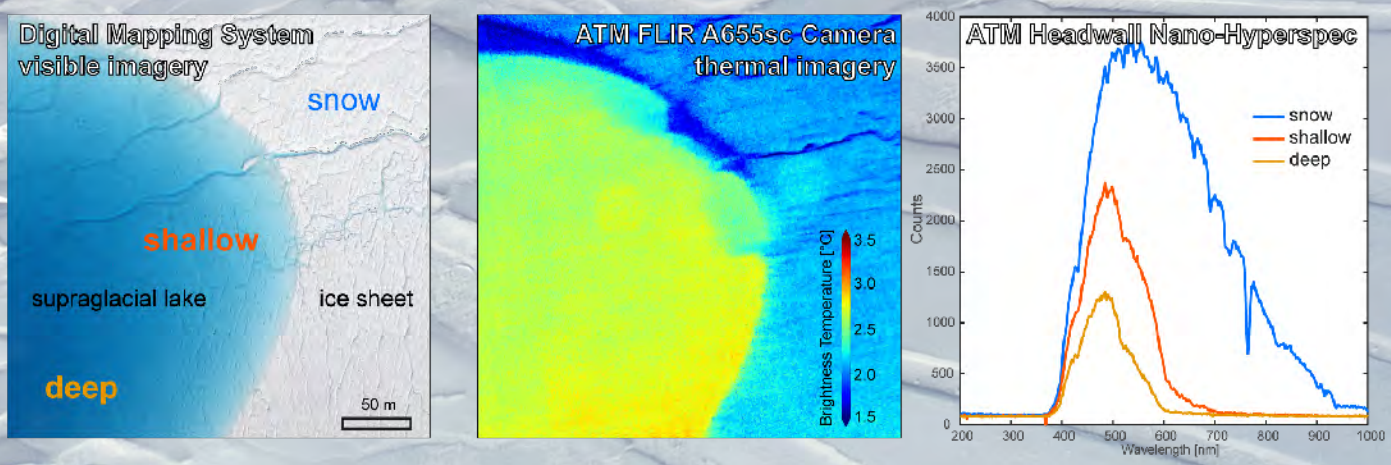
Auxiliary Instrument Science Applications

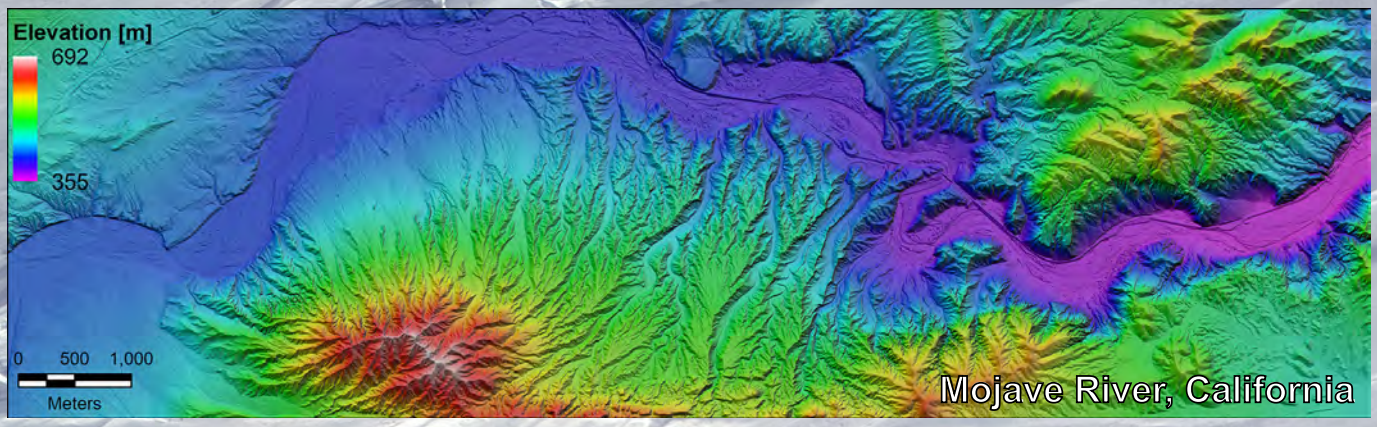


Thermal Imaging: ATM's KT-19 (left) and FLIR (right) surface temperature measurements over a sea ice lead in the Arctic Ocean. Labels: a) Thermal images reveal sea ice thickness changes with different temperatures. b) Temperature gradient across edge of lead. c) The thermal image reveals very thin ice that is difficult to identify in the optical image (left) and can lead to a bias in ice thickness estimates. d) Small-scale features can be resolved with this camera. The data set can be used for studying heat transfer and other physical processes at high spatial resolution spanning entire ocean basins. ATM's KT-19 skin temperatures (left) **were used to validate VIIRS data from the Suomi NPP mission.**

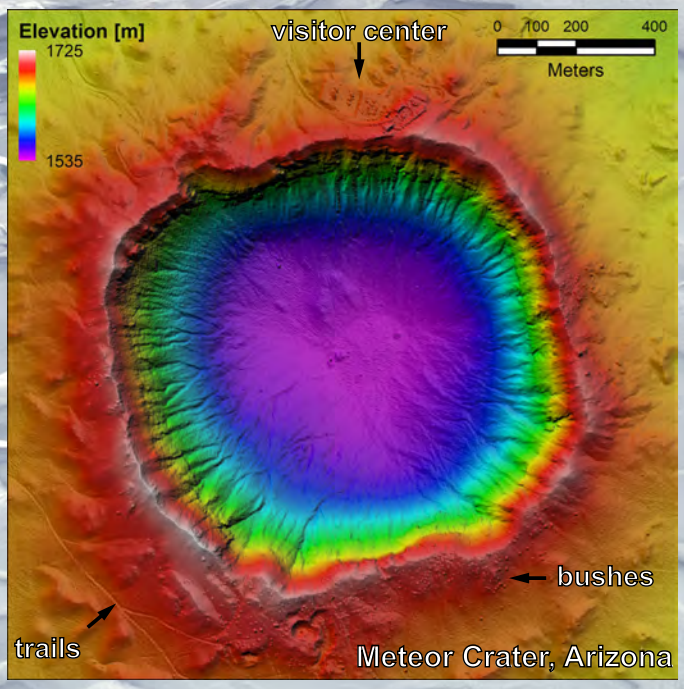


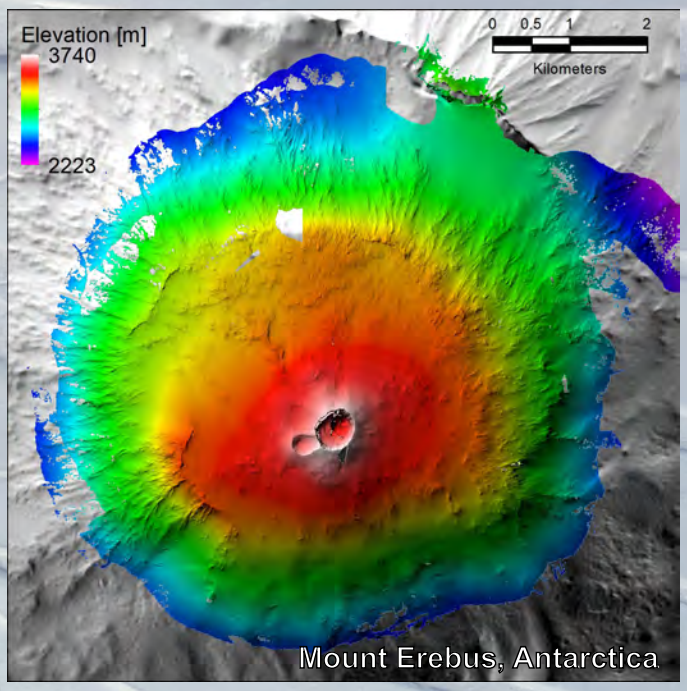
Supraglacial Lake on Greenland Ice Sheet: surveyed on 07/19/2017
Left panel: visible imagery of a supraglacial lake on the Greenland Ice Sheet. ATM's CAMBOT camera creates images equivalent to the DMS image shown, but was not installed for this campaign because of space constraints.
Center panel: thermal image of the lake and surrounding ice surface.
Right panel: example spectra over deep and shallow parts for the lake and the snow surface marked in left panel. This data set was acquired with a previous version of the hyperspectral imager. ATM has since upgraded to an instrument that covers a spectrum between 400 – 2500 nm.

Geomorphology Applications



Stream bed morphology. ATM topography of the Mojave Rive in California characterizes river channel morphology, width, fluvial patterns, slope, and other physical attributes for studies of flood frequency and inundation levels.

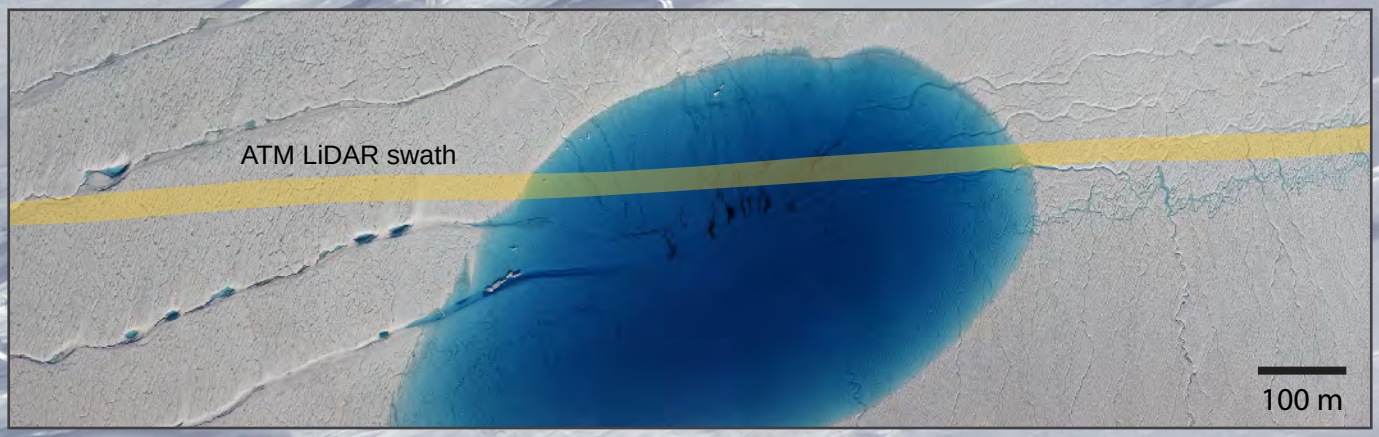




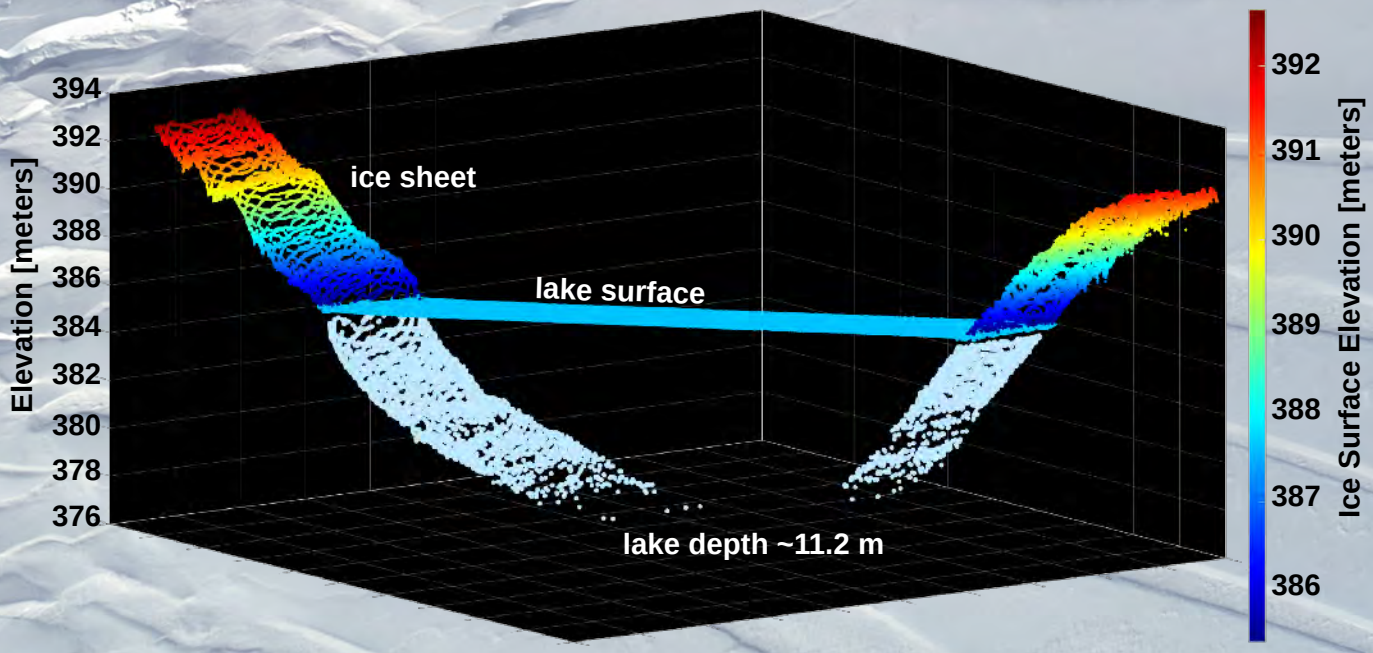
Impact crater geomorphology: ATM's high-resolution DEM of Meteor Crater in Arizona has been used to study slopes, roughness, ejecta volumes, etc. for planetary crater studies both for study of geomorphology and for guiding the design of landing craft on outer planets.

Volcanic Structure: Mount Erebus is an active volcano located in Antarctica. ATM's high-resolution DEM of the caldera has been used to map volcanic features such as lava channels, lava lakes, volcanic cones and active vents (Csatho *et al.*, Journal of Volcanology and Geothermal Research, 2008).

Bathymetry Applications



Supraglacial lake and meltwater channels on the surface of Hiawatha Glacier in Greenland. The lake is about 600 m wide. Natural color image mosaic using data from NASA's Digital Mapping System (DMS). ATM's CAMBOT camera creates images equivalent to the DMS image shown, but was not installed for this campaign because of space constraints.



ATM's muti-trigger waveform recording can be used for bathymetry processing by calculating the range and direction using refractive index in water from multi-return waveform data. The image shows depth estimates of the supraglacial glacial lake shown above, which together with auxiliary instruments can be used to calibrate spaceborne methods (Page 6).

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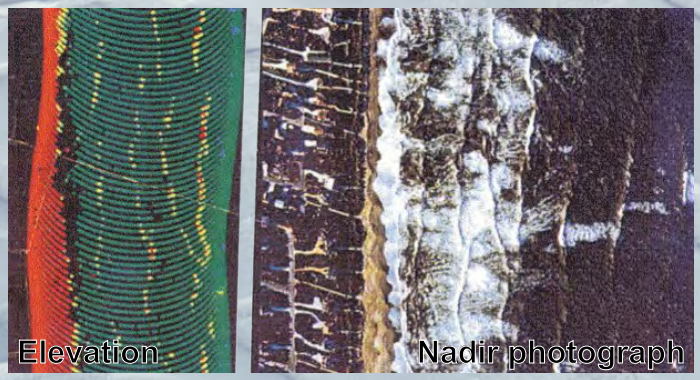
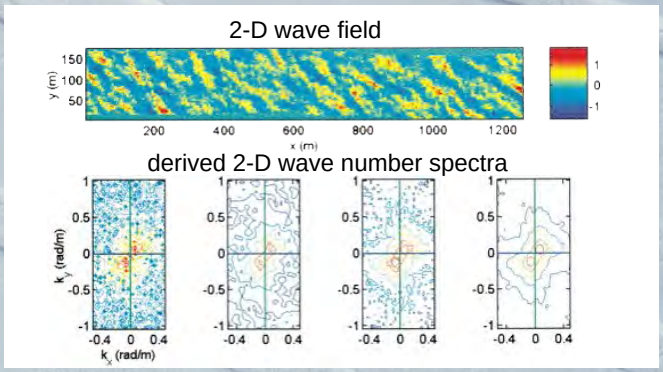
Beach Erosion and Ocean Wave Mapping

ATM LiDARs have twice mapped 80% of the conterminous US coastline to quantify beach erosion following major storm events. ATM also mapped parts of the Alaskan coastline. Below is an example of beach erosion near Esplanade Drive in Pacifica, California following an El Niño event. For more visualizations go to https://svs.gsfc.nasa.gov/645.

Study of wave characteristics affected by wind and bathymetry. Examples from Duck94 and Sandy-Duck97 experiments at Duck, NC. Reference: Airborne Scanning Lidar Measurement of Ocean Waves, P.A. Hwang, W.B. Krabill, W. Wright, R.N. Swift, E.J. Walsh, 2000: Remote Sensing of Environment, 73:234-246





ATM data products available from NSIDC

LiDAR wide scanner 532 nm

- L1B - point cloud spot elevation measurements (https://nsidc.org/data/ILATM1B)
- L2 - resampled and smoothed elevation measurements (https://nsidc.org/data/ILATM2)
- L4 - surface elevation rate of change measurements (https://nsidc.org/data/IDHDT4)
- L1B - elevation with waveforms (https://nsidc.org/data/ILATMW1B)

LiDAR narrow scanner with co-located 532 nm and 1064 nm footprints

- L1B - 532 nm point cloud spot elevation measurements (https://nsidc.org/data/ILNSA1B)
- L1B - 532 nm elevation with waveforms (https://nsidc.org/data/ILNSAW1B)
- L1B - 1064 nm co-located waveforms (https://nsidc.org/data/ILNIRW1B)

The **ATM waveform data products are similar in format and structure to ICESat-2's** standard data products. The format is implemented using the **HDF5 standard** as defined by the HDF® Group. The waveform data products **include additional documentation, instrument calibration** and transmit and return/receive waveform data for each laser shot in over 70 data fields. **Waveform products are particularly interesting for analyzing complex surfaces.** Complex return waveforms may be of particular interest in regions of sea ice ridges, subsurface ice surfaces (near icebergs for example, and over land and sea-ice melt ponds and other research applications.

Natural color digital imagery (CAMBOT)

- L1B - orthorectified, geolocated natural color images (https://nsidc.org/data/IOCAM1B)

Surface temperatures from KT-19 infrared radiation pyrometer

- L1B surface temperature measurements (https://nsidc.org/data/IAKST1B)

In addition to ATM's standard data products customized products, such as thermal imaging and hyperspectral products can be created that meet specific research needs.

Software tools: in addition to ATM's own software tools (https://atm.wff.nasa.gov) there is a growing number of open-source, third-party tools available for downloading and working with ATM data products:

- Cryosphere Altimetry Processing Toolkit: https://github.com/fspaolo/captoolkit
- IceFlow: https://github.com/nsidc/NSIDC-Data-Tutorials/tree/main/notebooks/iceflow
- Tyler Sutterly's NSIDC subsetter tools: https://github.com/tsutterley/nsidc-subsetter
- Point Data Abstraction Library (PDAL): https://pdal.io/stages/readers.qfit.html#readers-qfit