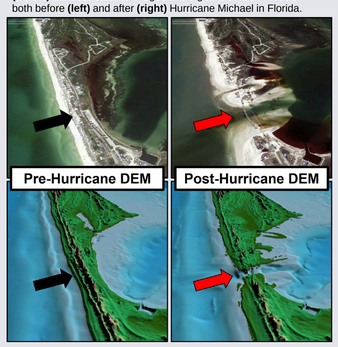
IVERT: The ICESat-2 Validation of Elevations Reporting Tool

Michael MacFerrin[1,2], Matthew Love[1,2], Christopher Amante[1,2], Kelly Carignan[1,2], Elliot Lim[1,2]
[1]Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder
[2]National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI), Boulder, CO

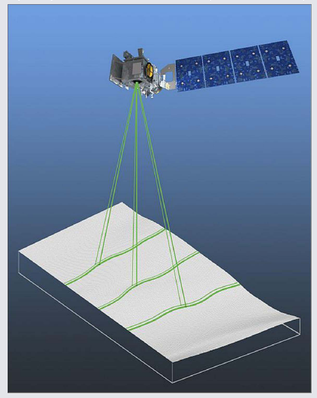
Introduction

(Below) LandSat satellite images and digital elevation models both before **(left)** and after **(right)** Hurricane Michael in Florida.

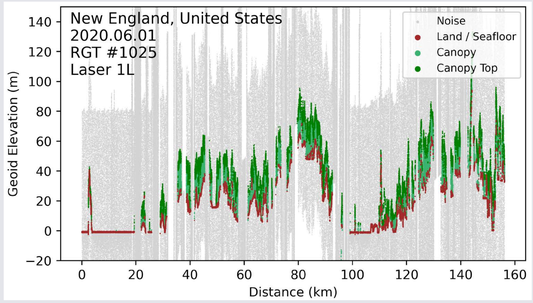


CIRES' Coastal DEM Team produces bare-earth seamless digital elevation models (DEMs) of coastal regions for disaster management and infrastructure planning. To measure the statistical accuracy of these DEMs, the team has recently developed the ICESat-2 Validation of Elevations Reporting Tool (IVERT) using photon-counting point cloud data from the National Aeronautics and Space Administration (NASA)'s Ice, Cloud, and Land Elevation Satellite 2 (ICESat-2). The Coastal DEM team includes results from IVERT in quality-assessment reports and distributes them publicly along with the DEMs through NOAA's National Centers for Environmental Information (NCEI).

(Below) Render of the ICESat-2 Satellite (credit: NASA GSFC)



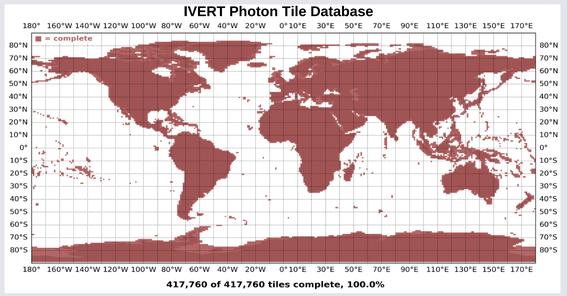
IVERT Database



(Above) An ICESat-2 photon point cloud over the Boston, Massachusetts area, with classified photon categorizations.

To rapidly access ICESat-2 photons, IVERT has pre-processed nearly a trillion geo-tagged and classified photons into a geographically-optimized database. ICESat-2 photons have been pre-classified with noise and low-accuracy artifacts removed, providing an optimized dataset for DEM validation. Using this database, IVERT retrieves photon data within seconds that would otherwise take hours of downloading, processing, and subsetting on a user's machine. IVERT can automatically update its back-end database with new processed photon data when such data is available from the National Snow and Ice Data Center (NSIDC).

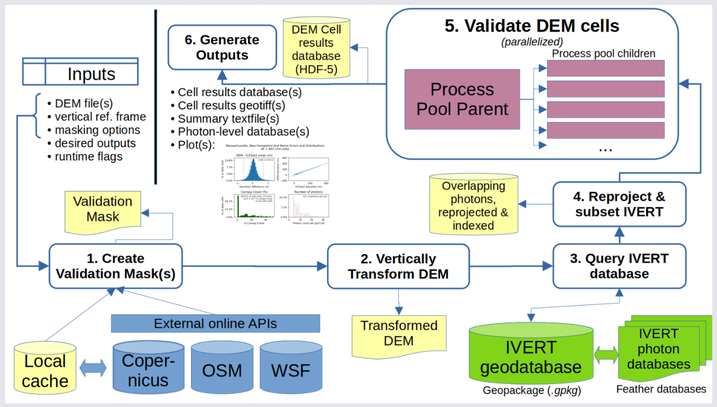
(Below) Global map of IVERT photon tiles for rapid spatial query.

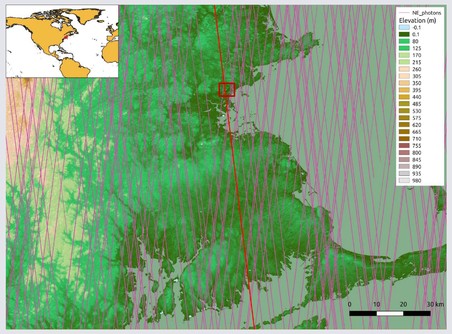


IVERT Workflow and Tools

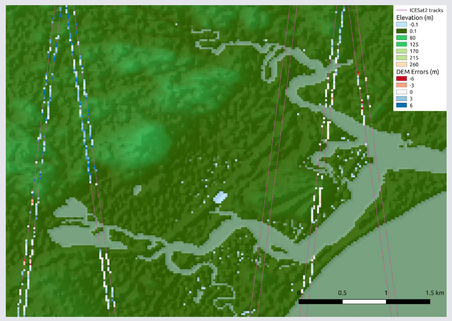
IVERT generates validation and error statistics for DEMs anywhere in the world. Users can submit a geolocated DEM along with a set of optional parameters defining what types of results they wish to receive and how they should be processed. IVERT has the capability to automatically perform vertical and horizontal transformations of the data for direct apples-to-apples comparison to ICESat-2 photons, generate validation masks (*see "Automated Masking", right*), query all the ICESat-2 data available to validate the DEM(s), and spin up a managed process pool of worker processes to perform the validations.

(Below) Workflow diagram of IVERT validating a single DEM. This does not include the client-server cloud architecture.



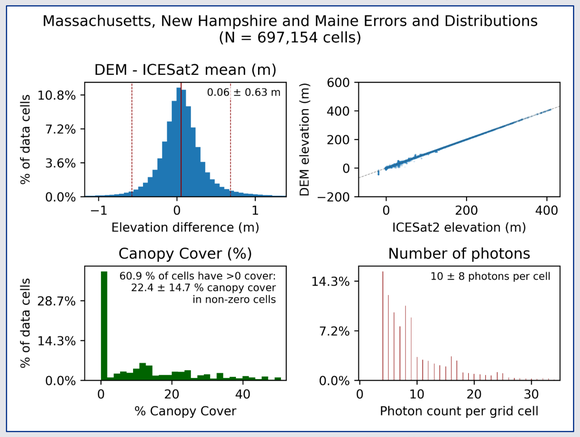


(Above) A map of ICESat-2 orbit tracks over a CopernicusDEM tile.
(Below) Zoomed-in portion (red box from above) of the CopernicusDEM tile with IVERT-derived error estimates.



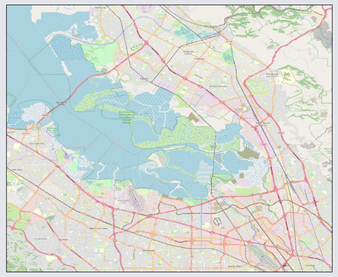
Users may select from a variety of outputs for IVERT. In addition to an automatically-generated summary plot (below) and text-file, users can opt to receive geo-located error maps mapped to the DEM grids, and databases of individual data points (both at the grid-cell level and/or the ICESat-2-photon-level) allowing users to post-process data themselves. Users can submit commands to return portions of IVERT's pre-processed photon database (see "IVERT Database", *top-right*) for other uses, or to command IVERT to update its database with new data from ICESat-2.

This flexibility allows IVERT's users to employ IVERT as a tool for a wide range of possible uses, not limited to its primary mission of DEM validation.

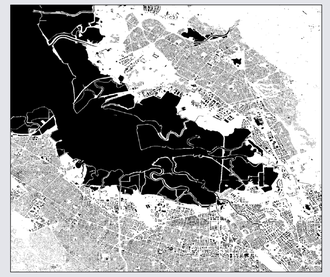


(Above) Summary plot of IVERT results for a collection of high-resolution coastal DEM tiles.

(Below) Map of Santa Clara, California (OpenStreetMap)



(Below) IVERT Validation Mask Map of Santa Clara, California, with ocean, lakes, large rivers, and urban structures masked out.



Automated Masking

When a DEM (or set of DEMs) is submitted to the IVERT tool for processing, IVERT automatically queries several online Application Programming Interfaces (APIs) to create a mask of where ICESat-2 should be used for validation. This mask filters out anywhere that ICESat-2 may provide erroneous information, such as oceans, lakes, large rivers, and the rooftops of urban structures, and provides an "apples to apples" comparison between ICESat-2 bare-earth returns and DEM elevations.

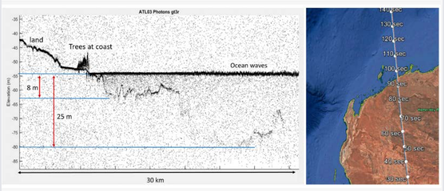
Cloud Migration

IVERT is being migrated from a high-performance computer into an Amazon Web Services (AWS) cloud environment managed by the NOAA Cloud Computing Framework (NCCF). With credentials, users can access IVERT with a lightweight client-side script from their local machines, requiring no dedicated hardware. The cloud environment enables IVERT to rapidly scale up for jobs of arbitrary size and computational complexity. IVERT's cloud migration is currently scheduled for completion in mid-summer 2024.

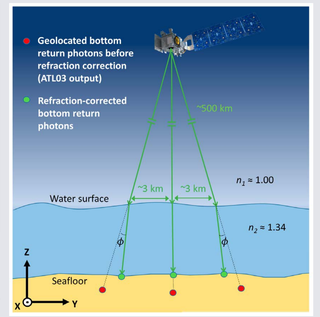
Availability and Future Work

IVERT code is publicly available for analysis and re-use on the CIRES DEM GitHub repository at https://github.com/ciresdem/IVERT. Many of IVERT's supporting tools are housed in the CUDEM repository at https://github.com/ciresdem/cudem. Presently, IVERT's cloud functionality is only available internally to CIRES researchers during its migration to NCCF's cloud environment, With additional support we hope to eventually host a public interface allowing anyone with an AWS cloud account to access IVERT's database and tools.

Figure 8. Geolocated bottom return photons for the North West Australia (western Pilbara region) site.



A near-term feature upgrade for IVERT is to use ICESat-2's green laser to penetrate water columns, allowing the validation of near-shore bathymetry in addition to IVERT's current land-only validations. This feature uses the University of Texas' Classification of Sub-aquatic Height Extracted Photons (C-SHELPh) module to identify and geo-correct ICESat-2 photons for bathymetric returns (*see images, right*). C-SHELPh has already been worked into the CUDEM tools and is currently being integrated into IVERT to allow rigorous validations of IVERT for both topographic and bathymetric data validations.



(Above, left) Diagram of an ICESat-2 flight line. **(Above, right)** Schematic of ICESat-2 derived bathymetric measurements. Both images from Parrish, et al (2019) *(below)*.

Parrish, C.E.; Magruder, L.A.; Neuenschwander, A.L.; Forfinski-Sarkozi, N.; Alonzo, M.; Jasinski, M. Validation of ICESat-2 ATLAS Bathymetry and Analysis of ATLAS's Bathymetric Mapping Performance . *Remote Sens.* **2019**, *11*, 1634. https://doi.org/10.3390/rs11141634

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