



catherine.gosmeyer@nasa.gov

# CHARACTERIZING ERROR IN THE VERIFICATION PROCEDURE OF ICESAT-2/ATLAS'S LEVEL-1B PRODUCT

C.M. Gosmeyer, A.J. Martino, M.R. Bock, J.E. Lee

NASA Goddard Space Flight Center

Abstract  
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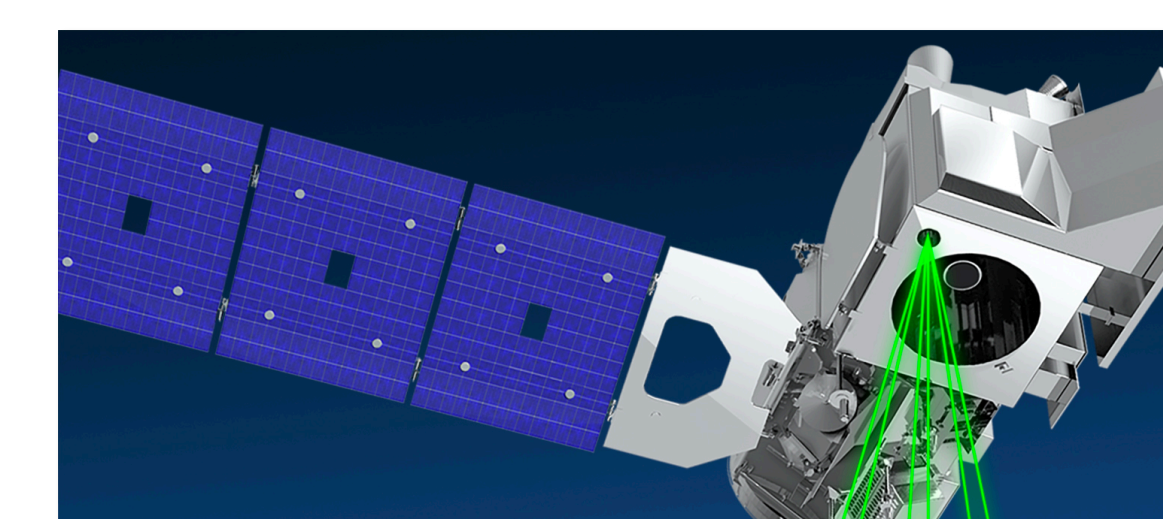
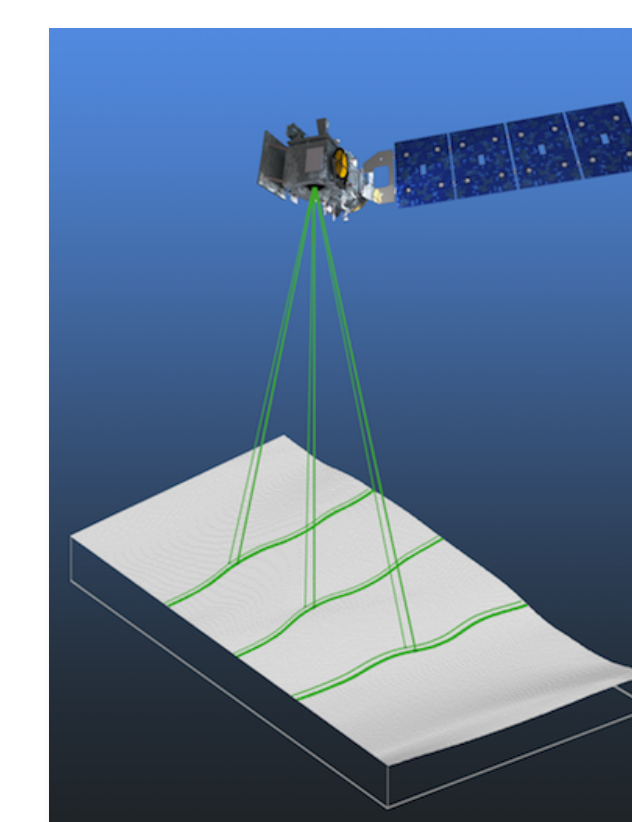
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## BACKGROUND

- Photon time of flight (TOF) is the primary calculation provided by the ICESat-2/ATLAS's level-1B product (L1B).
- To derive elevations with centimeter-level precision, TOF in L1B must have picosecond-level precision.
- We need characterize acceptable precision in all 25+ contributing calculations and calibrations to estimate how well we can expect the L1B TOFs to match independently calculated TOFs.
- Besides TOF, the L1B HDF5 file stores 1380 calculated and pass-through fields, including component temperatures, laser energies, flag settings, calibration selections, and so on, whose acceptable precision errors need to be characterized and verified as well.
- Goal of verification is to bring L1B code and algorithm description document into agreement by use of an independently written software suite.

## ICESAT-2

- NASA's Ice, Cloud, and Elevation Satellite 2.
- Launched 15 Sept 2018.
- Three-year nominal mission.
- Near-polar orbit, with 91-day repeat ground track.
- Specialized data products for sea ice, land ice, inland water, vegetation, ocean, and clouds.



## ATLAS

- Advanced Topographic Laser Altimeter System.
- Sole science instrument on ICESat-2.
- 532-nm laser, 10,000 pulses/second, split into six beams.
- Measures times of flight along six tracks on Earth's surface, which are converted to elevations with cm-level vertical precision.

## LESSONS LEARNED

- Issue Tracking:** Share with all parties a verification status table with one row for each field; over 400 of L1B's 1380 HDF5 fields had tracked issues (~20% calculation errors; ~80% metadata errors). Defining this table and committing to upkeep should be first step.
- Consistency of Precision:** If the final result is declared 64 bits, ensure all intermediate calculations and inputs are also 64 bits. Mixing 32 with 64 accounted for >50% of L1B's calculation errors.
- Intermediate Steps:** Build into both the verification code and the production code an easy means for reporting intermediate calculations to their full machine precision (no rounding on print).
- Self-Documenting Code:** All coded calculations should be human-readable and traceable to the primary documents (e.g., variable names that match algorithms'; do *not* invent new nomenclature).
- Open Software:** Store all software in a shared remote repository.

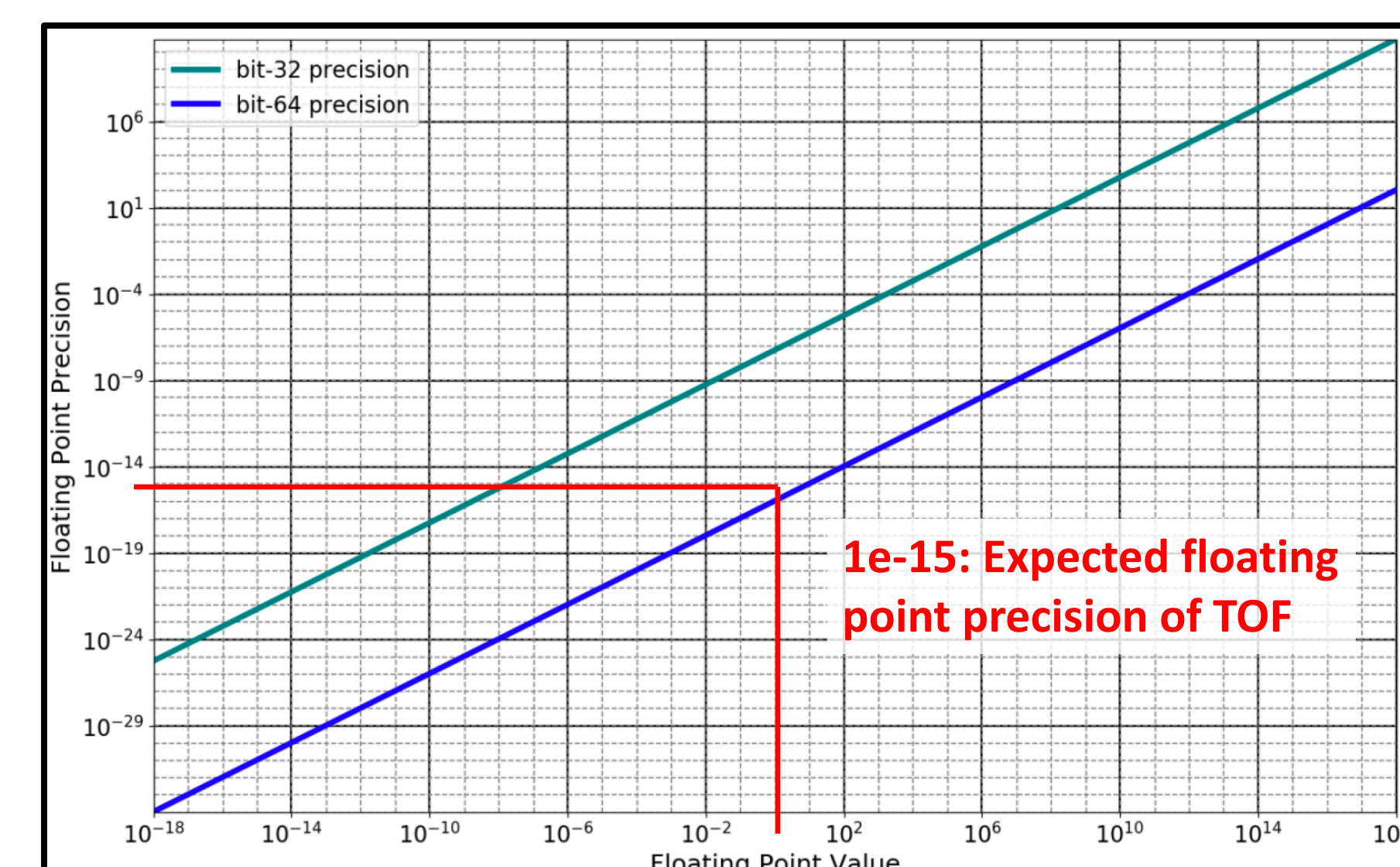
## EVALUATING ACCEPTABLE PRECISION & ERROR

- Exact match to last decimal place not realistic! Need to quantify how close is *good enough* for a L1B value and a verification value to be considered a match. This analysis is critical for TOF because desired reproducible precision (1e-12 sec) approaches expected machine 64-bit precision (1e-15); see **Figure 1**.

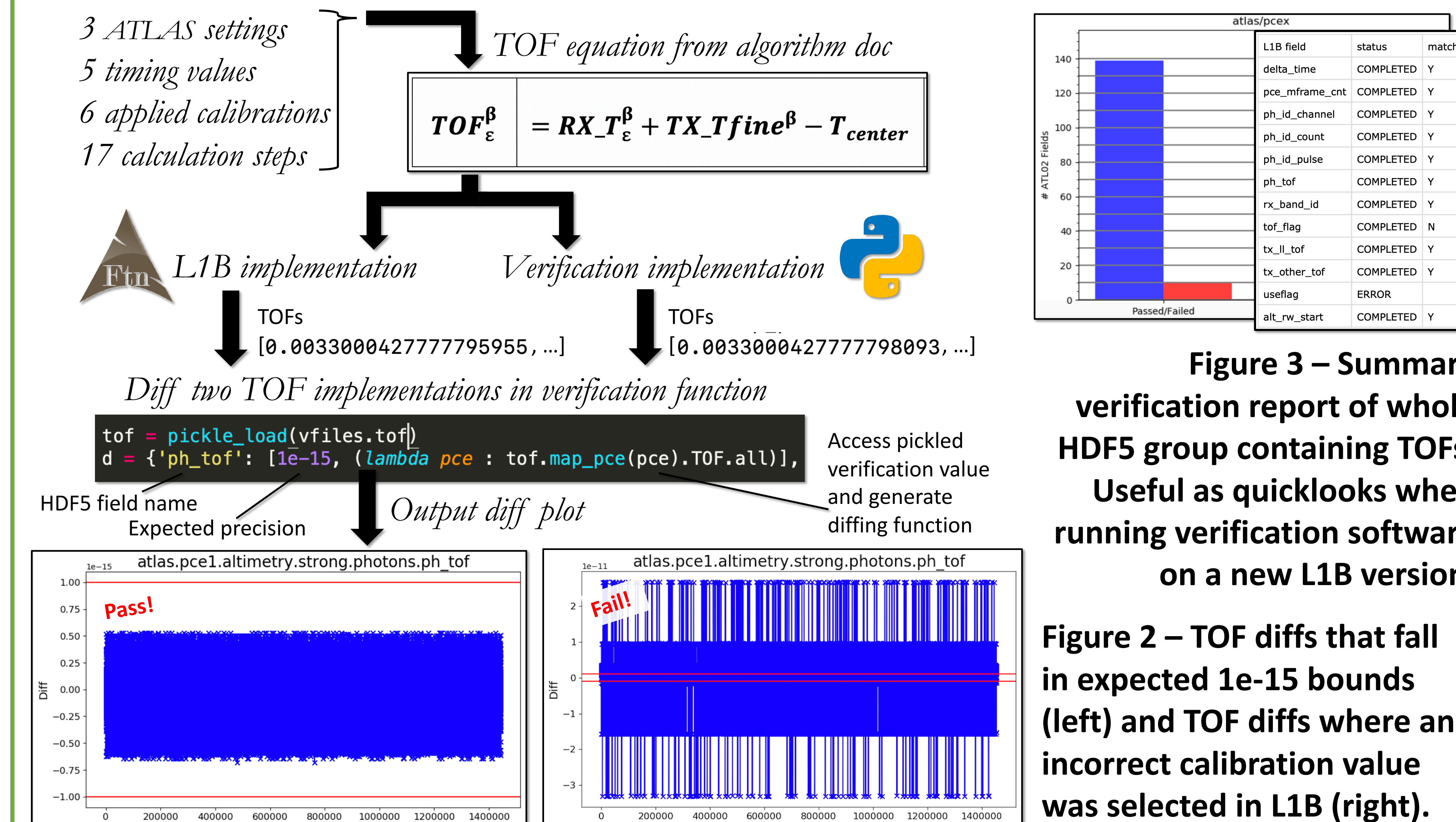
Error to minimize	Action	Justification
Programming language biases	L1B software is in Fortran; write verification software in Python	Precision differences well-documented; known that final floating points can vary somewhat
Measured/reported precision	Default to this precision before the machine precision	Neglecting to first quantify measured/reported precision has resulted in time wasted
Output precision	Pickle (serialized object) the executed verification software instead of writing to a file (e.g., HDF5 format used by L1B)	The verification objects are pickled and all attributes retain the exact form and precision which they had in the calculation; no chance of a formatting mistake; attributes can be directly compared with the appropriate field in the L1B HDF5 file
Algorithm to verification code implementation	As much as practical, variable and functions names match those given in algorithm document	Makes verification code easily traced to the algorithm document
Verification output to L1B output comparison	Write a dictionary for each L1B HDF5 field that maps it to a pickled verification attribute	Makes verification code's attributes easily traced to the L1B HDF5 fields; for added readability same dictionary contains the field's expected precision

- Want to minimize all errors so only remaining errors likely due to differences between the two codes' implementations of algorithms. Above table illustrates this process.
- By evaluating the precision each field *should be*, we were able to catch implementation errors that otherwise may have been overlooked and propagated into the science products.

**Figure 1 – Theoretical machine precision of both 32 and 64 bit representations for a given floating point value.**



## VERIFYING PHOTON TIME OF FLIGHT



L1B field	status	match?
delta_time	COMPLETED	Y
pce_mframe_cnt	COMPLETED	Y
ph_id_channel	COMPLETED	Y
ph_id_count	COMPLETED	Y
ph_id_pulse	COMPLETED	Y
ph_tof	COMPLETED	Y
rx_band_id	COMPLETED	Y
tof_flag	COMPLETED	N
tx_ll_tof	COMPLETED	Y
tx_other_tof	COMPLETED	Y
useflag	ERROR	
alt_rw_start	COMPLETED	Y

## RESOURCES

- Level-1B Algorithm Theoretical Document: [icesat-2.gsfc.nasa.gov/science/data-products](https://icesat-2.gsfc.nasa.gov/science/data-products)
- ICESat-2 public website: [icesat-2.gsfc.nasa.gov](https://icesat-2.gsfc.nasa.gov)
- ICESat-2 data archive: [nsidc.org/data/icesat-2](https://nsidc.org/data/icesat-2)
- Technical video: [youtube.com/watch?v=aYRqkdYJRr0](https://youtube.com/watch?v=aYRqkdYJRr0)

