Part 1: Question & Answer Session

Please type your questions in the Question Box. We will try our best to get to all your questions. If we don't, feel free to email Erika Podest (erika.podest@jpl.nasa.gov).

Question 1: How are the Doppler LiDARs used for wind component measurements different (fundamentally and/or technically) from the TLS?
Answer 1: Doppler LiDAR's measure the doppler shift from atmospheric properties, which is related to their speed and allows for their velocity to be calculated. This is achieved by mixing the return signal with a reference laser beam so that the onboard signal processor can determine the Doppler frequency shift from the spectrum of the mixed signal. TLS systems do not use a reference laser beam and hence do not measure the Doppler shift in the received signal.

Question 2: I am wondering if the Earth's speed is taken into consideration in the case of spaceborne LIDAR systems?
Answer 2: For ICESat-2 and GEDI, we take into account the relative velocity of both the Earth and spacecraft when geolocating the LiDAR returns.

Question 3: Is it possible to assess vegetation health (forest infested with insects) through LiDAR?
Answer 3: It is not directly possible, unless the damage has actually impacted the structure of the forest. Insect damage is usually detectable using multispectral or hyperspectral sensors that are sensitive to nearIR reflectance in the leaf cell. With GEDI waveforms, you may see differences in the waveform structure itself.

Question 4: What is the height resolution/accuracy we can achieve from LIDAR?
Answer 4: The height resolution/accuracy is a function of the instrument characteristics (e.g. pulse sampling rate, detector capabilities, etc.) as well as how well/dense a surface is sampled. That is, if a surface (let's assume trees) is sampled with lots of points -then the more points on that surface the greater the likelihood that the surface is sampled accurately. With ICESat-2, we are observing terrain height estimates with an accuracy <0.5m RMSE.

Question 5: I was wondering, is there an openly available algorithm or a repository of algorithms dedicated for full waveform lidar filtering to remove haze, dust etc. and extract useful vegetation structure information?
Answer 5: I believe that there are some open tools developed for analysis of GEDI waveforms (GEDIpy). We will be covering GEDI next session as well as providing a demonstration of the data.

Question 6: On the comparison between LiDAR and RADAR, won't the optical (visible) wavelengths used by the LiDAR as the probing signal be affected by absorption by the plant canopy apart from being reflected/backscattered in a stricter sense?
Answer 6: With IceSat-2, we do get the photons that are reflected back, but not all of the photons. In terms of differences, there is a large amount of reflected data.

Question 7: How do you distinguish the return from clouds or other atmospheric disturbance in the LiDAR ICESat-2 data?
Answer 7: Clouds and things like low fog are definitely challenging. For clouds that are significantly higher than the ground, those are easy to reject solely upon their heights and they are not included in ATL08. Low clouds or fog is one of the more challenging issues. Photons from fog look similar to photons from vegetation. It is something that the science team is trying to address within the data products but it is possible that there are ATL08 heights that might be incorrect due to low lying clouds or fog.

Question 8: Do we need to take into account Earth's speed in the case of space-borne LiDAR?
Answer 8: Absolutely. The relative velocity of the spacecraft and Earth is a component of the geolocation algorithms.

Question 9: Are LiDARs used in cities/urban surveys and for agriculture the same?
Answer 9: Yes, in general the airborne lidar systems used for urban or more rural studies are the same systems, however, the acquisition parameters might vary depending upon the application. For ICESat-2 and GEDI, there is not a way to adjust the lasers or parameters dependent upon the surface type. For ATL08, we provide a landcover classification (as defined by MODIS) to help users interpret their heights.

Question 10: In the case of the 532 nm laser which is a green light, do we need to correct for the sunlight during daytime when we measure the intensity of photons back to the sensor during daytime?
Answer 10: Yes, and most ICESat-2 data products include metrics on the background rate of photons (in particular ATL03, 04 and 09 all include photon background rates).

Question 11: Following slide 10, can LiDAR's wavelength be in any part of the light spectrum or LiDAR only emits in two wavelengths at 532 and 1064 only? And, is there a particular reason why the wavelengths are 532 nm and 1064 nm? can I have a LIDAR at 1300 nm, for instance?
Answer 11: Other lidar wavelengths are possible (the CATS mission on the Space Station for example also had a 355 nm band). The transmitted wavelength is an active area of laser research, however laser emitting in the near IR and green have the most heritage in the space environment. 1064nm is a common wavelength used by most manufacturers of said products. 1550nm is also another common wavelength used as well in LiDAR applications.

Question 12: Multispectral data such as Landsat data, Radar data and Hyperspectral data is also used for the Lidar applications presented here. ..What factors should one consider to decide when to use Lidar data? If I can analyse a similar phenomenon using Multispectral (Landsat) or Microwave data, why should I consider using Lidar? would you state specific characteristics of Lidar data in comparison to Landsat/Hyperspectral/Radar data that would make one choose to work with Lidar data?
Answer 12: It really depends on the application in question. While Landsat or Hyperspectral data give excellent 2-dimensional data sets at a variety of wavelengths, lidar provides the third dimension (height) that can complement these other sensors. Of course radar can also provide height measurements, and has the advantage of not being attenuated by clouds. However, the Lidar footprints are often much smaller than radar footprints. Optical data identifies spectral properties very well in all conditions.

Question 13: Can LiDAR be used in oceanic bathymetric studies? Or is it only limited to land water like rivers and lakes? If it can, is it affected by waves? How is accuracy and precision?
Answer 13: ICESat-2 has elevation products for both ocean and inland water. In addition, there are researchers using ICESat-2 data to also study near shore coastal bathymetry. There are several peer reviewed publications on the derivation of

bathymetry at our website: https://icesat-2.gsfc.nasa.gov/publications. The accuracy we have seen from studies have been on par with other survey datasets.

Question 14: What is the spatial resolution for LiDAR data? Does the data collected from LiDAR satellites have a global coverage?
Answer 14: In the case of ICESat-2, coverage is from 88 degrees north to 88 degrees south. ICESat-2 takes one measurement every 70 cm (along track direction) in each of 6 beams. Since these beams are derived from footprints with an ~11m diameter, ICESat-2 data is sparse in the across-track direction (i.e. there are significant gaps between data) but is dense in the along-track direction. The inclination angle is 92 degrees.

Question 15: What is the advantage of LiDAR operating in 532 nm over 1064 nm or 1550 nm, especially in case of vegetation? Any particular reason why the wavelengths are 532 nm and 1064 nm? can I have a LIDAR at 1300 nm, for instance?
Answer 15: The laser wavelength is useful in that vegetation reflects differently at each wavelength. For example, the reflectance of vegetation at 1064 nm is greater than at 532 nm. So, if you were looking at a reflected waveform with a green laser and NIR laser, you would see a similar structure (in terms of the detected heights) however, the amplitude of the waveform at each height would be higher in the NIR waveform.

Question 16: In terms of data processing and analysis, what can you say about Lidar data as compared to Hyperspectral data, Radar data or Landsat data regarding complexity?
Answer 16: In my opinion, it really depends on what you are familiar with. The Landsat data products (for example) have reasonably intuitive user interfaces and a whole range of data products derived from the observations. Imagery tends to play nicely with GIS packages such as QGIS or ESRI products. Lidar tends to be not quite as user friendly, but interfaces such as openaltimetry.org aim to make ICESat-2 and ICESat data as user-friendly as possible.

Question 17: How suitable is ICESat-2 data for tropical forests (I mean high-canopy-density forests) biomass estimation, considering its 532 nm measurements and footprint/beams? And how about understory detection?
Answer 17: Tropical forests can be challenging due to the density of the vegetation and the relatively low sampling, but we have seen lots of ICESat-2 data yielding good

returns over tropical forests. The biggest challenge in the tropics that I've personally observed are due to clouds.

Question 18: Is it possible to combine the Icesat-2 observation with the GEDI data? What is the possible main challenge for combining those data?
Answer 18: Absolutely, that is the hope. There are some subtle differences with how the vegetation height metrics (e.g. RH50) are calculated on ICESat-2 and GEDI -but in general the relative canopy heights should be fairly comparable. The main challenges in intercomparing these data are the different locations of the ICESat-2 and GEDI data: since they are on different platforms with different orbits, some care needs to be taken to extract reasonably co-located data. A second challenge is in the geolocation uncertainty of the two products. If it is essential for your application that the two products are from the same location, one should consider the relative position uncertainties of the products (~6m for ICESat-2; ~15m for GEDI).

Question 19: What is the exact size of ICESat-2 LiDAR footprints?
Answer 19: ICESat-2's footprints are 11m (+/- 1.5 m, depending on atmospheric conditions) on the ground. Check out the 88-South Antarctic Traverse science expedition to assess the accuracy of surface-height data collected from space by ICESat-2: https://earth.gsfc.nasa.gov/cryo/campaigns/88-south-antarctic-traverse

Question 20: Please give an example of a ground-based LiDAR platform.
Answer 20: Terrestrial lidar scanners (https://www.unavco.org/projects/project-support/tls-support/tls-support.html) are used in many ground based lidar studies.

Question 21: Are you generating a baseline for each day of year and latitude for solar sourced stray photons, to later filter them out from LiDAR data?
Answer 21: ICESat-2 data classifies each photon as being a likely signal photon or a likely background photon (ATL03) for each track. We have looked at the background rate as a function of day or year, latitude and ground reflectance (a snow covered scene generates much higher background than a bare earth scene) but the variability in ground reflectance precludes a simple relationship. For example, the background photon rate in Denver Colorado was much different on Sunday after a gigantic snowfall than it is today after the snow has mostly melted.

Question 22: How difficult is it to differentiate solar photons from the surface ones? is it visually possible or does it require a specialized algorithm?
Answer 22: It's impossible to differentiate a solar photon from a surface photon based solely at the photon level. To distinguish them apart, we look at the proximity to neighboring photons with the assumption that photons reflecting from a surface will have a higher point spacing to neighboring photons.

Question 23: How do we filter the ICESat-2 data for day and night?
Answer 23: On the ATL08 and ATL03 data products, there is both a day/night flag as well as a solar elevation angle. All solar elevation angles below 0 degrees are night acquisitions.

Question 24: How to verify the ICESat-2 LiDAR data derived heights on ground?
Answer 24: What most folks do to validate the ICESat-2 heights is compare against airborne lidar or GPS derived heights of a surface. There are several peer reviewed papers that do exactly this linked through our website: https://icesat-2.gsfc.nasa.gov/publications.

Question 25: Can LiDAR be used to measure aerosol concentrations or smoke plume heights from fires?
Answer 25: Yes. The ICESat-2 ATL09 product provides metrics for the height and intensity of reflecting layers in the atmosphere. Determining if atmospheric reflections are due to water vapor clouds, smoke plumes, or aerosol is an active area of research.

Question 26: Which ICESat-2 product is best used for shallow water bathymetry?
Answer 26: ICESat-2 does not currently have a shallow water bathymetry product. Depending on your specific area of interest, the ATL03 photon cloud is available globally, and several papers have now appeared that describe different methods for bathymetric measurements from ATL03 (https://icesat-2.gsfc.nasa.gov/publications). In addition, the ATL13 inland water data product contains an experimental water depth metric for inland water bodies such as lakes and reservoirs. One of the mission's Early Adopters (PI: Christopher Parrish, Oregon State University) developed a project to map shallow water bathymetry using a fusion of Landsat 8 Operational Land Imager (OLI) and ICESat-2 ATLAS data: https://shallowbathymetryeverywhere.com/.

Question 27: In PhoREAL, can we process multiple HDF5 files at a time?

Answer 27: PhoREAL does support batch processing, but each file is analyzed individually. Each beam is processed on a beam by beam basis.

Question 28: Is there a version of PhoREAL for Linux? Thank you for your answer!
Answer 28: Yes, the source code of PhoREAL on GitHub can be run in a linux environment. It is python code.

Question 29: Can ICESat-2 data detect 2 meters height mangroves in shallow wetlands?
Answer 29: Yes, it certainly should be able to. I've observed shrub/woodlands in the 2m range in other locations. Uncertainty is usually found in heights of less than 1m. We invite you to share with us how you would use ICESat-2 data for this application! Check out the mission's Applied Users program: https://icesat-2.gsfc.nasa.gov/applied_user

Question 30: Is ICESat-2 data available on Google Earth Engine? Is there any plan to ingest the ICESat-2 data into a cloud computing platform, i.e. Google Earth Engine?
Answer 30: NASA is in the process of negotiating agreements with Google Earth Engine (GEE) and other cloud vendors. Until an agreement is in place, neither NASA or the DAACs can ingest data into the Google Earth Engine public data holdings. It is possible that Google will decide to ingest ICESat-2 on their own. There are active efforts to put ICESat-2 data into NASA's Earthdata Cloud as well as ICESat-2 data services (e.g. subsetting) and other ICESat-2 tools. This is a priority in our data migration strategy but there isn't a published date for user access at this time. There will be many announcements when it goes live. You can sign up for the ICESat-2 mailing list by sending an email to nsidc@nsidc.org with the subject line "ICESat-2 mailing list signup".

Question 31: How do ICESat-2 errors from water surfaces compare with errors in canopy elevations? Can this be used to find shorelines [lakes or large rivers] in forested areas? How deep can it penetrate the ocean?
Answer 31: It really depends on how calm or rough the water surface is. For leads in sea ice, several papers have shown that the water surface can be measured to the 1 or 2 cm level. Over open ocean where there are a variety of roughness of surface waves and the returned photon rate is much lower, the surface height accuracy is much lower, and on the order of a meter, similar to canopy elevations.

Question 32: Is there a limitation to the number of requests that can be made through the API?
Answer 32: For each API call, the maximum file limit for a synchronous request is 100, and the maximum limit for an asynchronous request is 2000. The asynchronous data delivery option will allow concurrent requests to be queued and processed without the need for a continuous connection; orders will be delivered to the specified email address. Synchronous requests will automatically download the data as soon as processing is complete; this is the default if no method is specified. You can learn more about the API and programmatic access at:
https://nsidc.org/support/how/how-do-i-programmatically-request-data-services

Question 33: How do you separate strong beams from weak beams?
Answer 33: The way that I do it is by beam number. Beam 1, 3, and 5 are the strong beams, Beam 2, 4, and 6 are the weak beams. Those beam numbers are consistent regardless of the satellite/spacecraft orientation.

Question 34: Can you please explain the beam-splitting again, i.e. 6 beams at ~3 km apart and pairs of beams at 90 m apart, etc.?
Answer 34: The ATLAS instrument generates a single laser pulse that is split six ways as the pulse leaves the spacecraft. These 6 beams are arranged into pairs: one pair of beams are in the center of the pattern, and neighboring pairs are ~3.3 km to the left and the right of the center beams. Within a pair, the strong and weak beams are spaced by 90m. We are able to derive the slope of the terrain surface between the two beams. This gives us a better understanding of local topography.

Question 35: Do we need to discard the data (ICESat-2) with high uncertainty?
Answer 35: That is entirely up to the specific application. For some studies, larger uncertainty is completely acceptable, while for the most exacting studies, any errors larger than ~10cm render the data useless. Each data product includes metrics on the height uncertainty to allow an end user to set their own threshold for what constitutes "good data".

Question 36: Can you please elaborate on the reason to have 6 laser beams? How can the user decide which beam to use?
Answer 36: The reason for 6 beams is to increase the spatial coverage of each ICESat-2 overpass. The arrangement of the beams was optimized for enabling ice sheet elevation change measurements. Depending on your application, one, some or all

beams may be appropriate. For example, when looking at data over a specific object (such as my mom's house) I only look at data from the beam that passes over her house. For other studies, such as the canopy height in Mendocino County, California, I use any and all available data.

Question 37: Is Lidar data only limited to canopies and not other vegetation like shrubs, grasslands, etc.?

Answer 37: ICESat-2 data collects data everywhere. The ATL08 data product reports heights associated with terrain heights as well as shrubs/tree heights. Vegetation heights that are <1 m are likely not to be detected easily (i.e. not a discernible) from the terrain surface. Check out the work by Early Adopter (PI: Nancy Glenn, UNSW Sydney/Boise State University) on the use of ICESat-2 data for improved terrestrial carbon estimates with semiarid ecosystem structure: https://icesat-2.gsfc.nasa.gov/early_adopters/early-adopters-14

Question 38: Why is there a significant variation in surface elevation and canopy height between the strong and weak beams?

Answer 38: The energy on the strong beams is 4 times the strength than the weak beam. This difference in energy results in more photons reflecting back from the surface than on the weak beam. The two beams within a beam pair are also measuring different surfaces, so in some cases the apparent height difference is real. The beams within a pair are 90m apart from each other.

Question 39: Is there a difference in canopy height between the downloaded .csv and the .hdf5 file?

Answer 39: No. The data is the same for all file formats. However, the .csv file downloaded through OpenAltimetry only includes key parameters like latitude, longitude, canopy height, and terrain height (along with a few others). If you want the full suite of parameters you will need to access the data using the native .hdf5 or other formats offered through NASA Earthdata Search (https://search.earthdata.nasa.gov/search) (i.e., NetCDF4, NetCDF3, ASCII, Shapefile). ASCII file downloads are limited to 2GB in size.

Question 40: How are the ICESat-2 data validated in regions with sparse ground measurements such as South Asia?

Answer 40: To date, there have only been a handful of validation studies in South Asia. Most of the project's validation efforts have focused on Antarctica, Greenland, and the *global ocean; with additional smaller target studies over Finland, and many smaller plots. See https://icesat-2.gsfc.nasa.gov/publications for a list of validation papers.*

Question 41: I may have missed something, but was a definition given for "granules"?
Answer 41: No. Sorry about that. "Granule" is a term used to describe a single data file. In the case of ATL08, a single data file will include about 1/14th of the along-track orbit of ICESat-2.

Question 42: Is there a gridded canopy height product? And if so, can you recommend how to access it?
Answer 42: Not yet, but there are plans for one hopefully later this year! :-)

Question 43: When you showed canopy cover maps based on ICESat-2, was that interpolated between the tracks, and how?
Answer 43: The canopy cover map that was shown in the introductory charts were produced from the GEDI data.

Question 44: Is ICESat-2 data for canopy height for the same region different as provided by GEDI canopy height? Is ICESat-2 going to produce biomass data like GEDI? If not, may I know when GEDI 04 data for biomass will be available? Could you please recommend a paper regarding forest biomass study using ICESat-2 data?
Answer 44: ICESat-2 collects data between 88 degrees north and 88 degrees south latitude; while GEDI collects data from ~52 degrees north and south. The difference is due to the different orbits of the two instruments. Many studies are using ICESat-2 to produce biomass estimates, however there is not an official ICESat-2 biomass product.

Question 45: How useful is it to combine ICESat-2 ground elevation and canopy height from variable dated ground tracks for localized project areas? What caveats should be taken into consideration? Use case is monitoring forest regrowth after a severe wildfire.
Answer 45: For monitoring forest regrowth after fire disturbance, I can imagine that the aggregation of data through time would depend on the expected rate of regrowth. I suspect this would depend on the specific species in question and would be an area of research to determine how much data to aggregate together before the signal you are seeking is averaged out.

Question 46: Can the LiDAR's data be used for assessing drought-induced mortality? Land subsidence? Understory vegetation?
Answer 46: We invite you to share with us how you would use ICESat-2 data for these applications! Check out the mission's Applied Users program: [*https://icesat-2.gsfc.nasa.gov/applied_user*](https://icesat-2.gsfc.nasa.gov/applied_user)

Question 47: When are ICESat-2 and GEDI going to retire?
Answer 47: ICESat-2 has fuel for at least another 10 years of orbit maintenance. As of today, ATLAS is happy and healthy (or as happy as a lidar gets anyway), though it is difficult to predict when it will stop working. As I understand it, GEDI is also happy and healthy, and will remain on the ISS for at least the next two years.

Question 48: Why does the PhoReal software need ATL03 and 08 as input to map canopy characteristics?
Answer 48: Many users with ATL08 data wish to take advantage of "mapping" the classification labels from the ATL08 algorithm back to the photon level- which then requires both data products.

Question 49: How can we integrate LiDAR with other data sources for landscape vegetation mapping?
Answer 49: Provided that both data sets include geographic coordinates, many software tools (QGIS) allow the data to be plotted together.

Question 50: From the vegetation height, how do we find the canopy density in a particular area of interest?
Answer 50: Canopy density (or I will refer to it as canopy cover) can be derived from lidar data- usually as the ratio of canopy energy relative to the total reflected energy. When analyzing full waveform data, this is how canopy cover is determined. With ICESat-2, canopy cover can be inferred by the number of canopy photons in an ATL08 relative to the total number of signal photons. However, because ICESat-2 is detecting just a few photons per shot (~1-2), there are several parameters that can change/impact that relationship to determine cover (~e.g. atmospheric attenuation, surface reflectance, etc.) In the future releases of ATL08, there will be a "woody vegetation" fractional cover value that is derived from the Copernicus data to help assist ICESat-2 users in interpreting their results.

Question 51: Can you comment on differences in water returns using ICESat-2: clear vs silty vs algal blooms. Given current lack of repeat coverage in mid-latitudes, I'm interested to hear about how to think about this kind of comparison.
Answer 51: Certainly the bathymetric returns measured by ICESat-2 are strongly impacted by the water clarity. To date, there have been a couple of papers (https://icesat-2.gsfc.nasa.gov/publications) attempting to use subsurface ICESat-2 returns to assess water clarity.

Question 52: Is there any effect of field slope on the direction of the returned beam? Is that treated differently within the cases of radar and Lidar data?
Answer 52: The ICESat-2 telescope has a relatively small field of view on the ground (~45 meters). So provided that some photons are reflected back to the telescope, ICESat-2 can measure steeply sloping surfaces. Although in those instances, many photons are indeed reflected away from the telescope, leading to lower numbers of signal photons.

Question 53: Hi NASA! This is the data we already are waiting for, and appreciate all of the amazing work to share this data. Just wanna ask, will this ICESat-2 satellite cover all of the earth surface? since its predicted lifespan is only 5 years CMIIW... Regards from Indonesia...
Answer 53: ICESat-2 collects data between 88 degrees north and south latitudes, and all latitudes in between. So it's not the entire Earth, but a lot of it.

Question 54: What current missions use discrete lidar or full waveform lidar?
Answer 54: GEDI uses a full-waveform lidar.

Question 55: I am interested in using ICESat-2 data for validation of InSAR/IfSAR generated CHM in my research. How accurate is ICESat-2 data (rmse 2-3cm)? Also please suggest related literature for reference.
Answer 55: Hello! You can find a number of studies assessing the ICESat-2 accuracy here: https://icesat-2.gsfc.nasa.gov/publications RMSE of 2-3 cm sounds pretty small, depending on the area / number of data points being collected.

Question 56: Hi, can you tell me please if I misunderstood the following? One ICESat-2's beam covers an area of 3x3 km2?

Answer 56: The ATLAS instrument generates a single laser pulse that is split six ways as the pulse leaves the spacecraft. These 6 beams are arranged into pairs: one pair of beams are in the center of the pattern, and neighboring pairs are ~3.3 km to the left and the right of the center beams. Within a pair, the strong and weak beams are spaced by 90m. So while all beams span 6.6 km from left to right, the 6 beams only illuminate a very small fraction of that distance.

Question 57: Regarding page 8 in Amy's presentation, can you clarify the difference between GT1 and GT3? Thanks!

Answer 57: GT refers to Groundtrack. The ATLAS laser is split into 3 beam pairs (Groundtrack 1, Groundtrack 2, and Groundtrack 3). The weak and strong beam for a particular GT will be labeled as "L" for Left and "R" for Right. The weak and strong beam however, will change as L or R depending upon the orientation of the spacecraft.

Question 58: How do I know whether the ATL-08 product may be affected by clouds?

Answer 58: It's tough to determine at times, particularly when looking solely at the canopy heights on the ATL08 data product. If a canopy height looks higher than might be expected -it could be due to a low cloud. For example, if all the vegetation height in a given area ranges from 20-25 m and all the sudden there are a few heights at 50 m, those could be due to a low cloud. In cases like this, often users might examine the data in the ATL03 photon cloud to get a sense of what might be contributing to the unexpected height.

Question 59: If someone wanted to study vegetation structure eg. If understory is present, Would it be useful to look at the ATL-03 product?

Answer 59: On the ATL08 data product, there are several relative height metrics that are correlated to the cumulative distribution of heights. If there is a large presence of low vegetation beneath and higher overstory, we would anticipate a RH10 or RH25 metric that is lower in height.

Question 60: Can you please tell more about the gridded Land/Canopy dataset - ATL18? I don't see it available in the dataset links mentioned for ATL08 for example.

Answer 60: Correct, we don't yet have the ATL18 data product. It's coming soon so stay tuned.