ICESat-2 Applications Workshop Report
NASA Goddard Space Flight Center
April 12, 2012

Molly Brown
Mark Carroll
Vanessa Escobar

ICESat-2 Applications Team

NASA Goddard Space Flight Center

Summary

The Ice, Cloud and land Elevation Satellite-2 (ICESat-2) Earth science satellite is the third of the tier 1 decadal survey missions and is scheduled for launch in 2016. Each of the decadal survey missions has been charged with involving the applications and community outreach programs in the mission development phase to ensure the highest possible impact is attained from the mission. The first ICESat-2 applications workshop was held on April 12, 2012 with the goal of bringing together the product developers and the community so that the mission can better understand and respond to their needs. The workshop was attended by over 60 people from scientific and technical communities interested in the mission as well as by members of the science team. This report summarizes the characteristics of the community who are interested in ICESat-2 data, and the discussions held during the workshop.

Prior to the workshop an online questionnaire was created and invitations to participate were included in the invitations to the workshop. The purpose was to give users a chance to provide direct feedback to the applications team. The preliminary results of that survey are summarized in this report and suggest that the users are excited about the prospects of ICESat-2 and are interested in how the ICESat-2 products will integrate into their current work.

The workshop was structured with a morning plenary session and afternoon breakout sessions. The morning plenary session was used to introduce the mission and the proposed products, while the afternoon session was an opportunity for interaction between the users and the product developers. The breakout sessions were divided into 3 themed areas, following the themes of the Science Definition Team (SDT), ice sheets/sea ice, land elevation/vegetation, and oceans/inland water/atmospheres. The breakout sessions provided feedback on 1) the suite of products that are planned, 2) the need for higher order products to be generated from the airborne and simulated data, 3) a critical need for accurate ancillary products to calibrate the planned products, and 4) the need of certain communities for near-real time products.

Overall, the feedback from attendees has been overwhelmingly positive. There is interest from the user community in starting an Early Adopter program, whereby users would have the opportunity to work with an SDT member during mission development. This complementary process gives the user access to developmental products while the product developer gains a partner in analyzing and assessing the data products as they are being developed. This program has been used with other decadal survey missions, including the Soil Moisture Active Passive mission (SMAP), and the applications team will work over the coming year to build a similar program for ICESat-2. The applications workshops are planned annually during the pre-launch phase, with additional focus sessions during the year. The first focus session will be a joint session with SMAP to be held in Fairbanks, Alaska September 18-20, 2012. The ICESat-2 applications group will continue to work with the ICESat-2 SDT and the community to form an applications working group to assist the mission during its development phase. Through launch, the ICEsat-2 mission will use the feedback and guidance provided by the applications working group to better understand how different thematic groups will use mission data.

Table of Contents

1. Introduction

The Ice, Cloud and land Elevation Satellite-2 (ICESat-2) Earth science satellite, scheduled for launch in 2016, is the next-generation laser altimeter and the successor to the original ICESat satellite, which provided for the first time high resolution ice and land elevation data from space. In contrast to the design of the first ICESat mission, ICESat-2 will use a micro-pulse multi-beam approach, which will enable improved elevation estimates over high slope areas and very rough crevassed areas of the ice sheets, leading to improved detection of changing sea and land ice elevation, as well as information on vegetation density, inland water and land elevation. The data from ICESat-2 will be useful to a broad community of scientists, decision makers and those implementing policies in a variety of fields. This report provides a summary of the first ICESat-2 workshop, which focused on improving the knowledge of and communication with potential users of the mission data.

In 2006, NASA conducted an external review to gain user feedback on the importance of potential future missions to the overall science community. This review resulted in the "Decadal Survey" (http://science.nasa.gov/earth-science/decadal-surveys/) and has become the blueprint for how missions engage with its users before the satellite is even launched. The report stated that it was not enough to collect the data and provide it to the scientists who do research, but also that it should involve applications and applications research (defined below) at the mission level during development in order to maximize the utility and impact of the data collected.

- ***Applications*** are defined as innovative uses of mission data products in decision-making activities for societal benefit.
- ***Applications research*** will provide fundamental knowledge of how mission data products can be scaled and integrated into users' policy, business and management activities to improve decision-making efforts.

Providing actionable data to decision makers has become a priority as world leaders try to understand the Earth system and the challenges imposed by the climate and climate change. Applications have become an integral part in converting the data collected into actionable knowledge that can be used by leaders to form policy. For ICESat-2, an applications team has been established that is working to bring the community of practice (the community of users currently engaged with NASA earth science data) together with the product developers to ensure that the planned products are going to meet the needs of the broader community (which includes both science and applications users).

The goal of the first applications workshop was to introduce the mission to the community of practice and to get feedback from this community regarding the plans for ICESat-2. The meeting was attended by over 60 people, including Science Definition Team (SDT) members and the community. Science presentations were made by the product developers and scientists working with the mission. Breakout groups for water and atmospheres, land elevation and vegetation, and ice and sea ice provided opportunities for the users to provide direct feedback. In addition, the applications team created an online professional review with a series of questions that allowed the team to get direct feedback in specific areas including product selection, product latency, and formats and projections. At the time of this report there were over 25 responses to the questionnaire that remains open to continue to collect information as the community expands.

In the following sections we will summarize the mission, science presentations, and the breakout sessions. We will follow with a summary of conclusions and action items derived from the user feedback in the breakout sessions and the survey results.

2. Mission Background and Heritage

2.1. ICESat Heritage Mission

The original ICESat mission was launched in 2003 with a 3-year mission life and science goals to measure the rate of change of the world's ice sheets and sea ice. ICESat was the first space borne LiDAR system for Earth science and provided a synoptic set of elevation measurements that was used to measure change in ice sheets, sea ice, land elevations and tree canopies. The mission operated in campaign mode and continued collecting data until it was decommissioned in 2009. The Geoscience Laser Altimeter System (GLAS) was a single beam laser that collected data during specified campaigns with consistent repeat coverage over the poles and at strategic locations at lower latitudes (the system was operated in campaign mode to conserve the laser and prolong the mission). The measurements collected succeeded in the primary mission objectives by providing insight into where and how fast the Earth's ice is changing. In addition to the primary objectives, the mission provided detailed information regarding global standing carbon stocks, and terrestrial water storage in both water and snow.

ICESat data products are distributed by the National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC) in Boulder, Colorado. With nearly 10 years of distribution statistics, the predominant products requested by users are the L1 raw data (from which any product can be created) and the Level 2 land elevation data (from which derived products such as canopy height and ice sheet elevation can be derived). This suggests that the primary users of the ICESat data were science data users, however it is also clear that these users produced and distributed results that have been utilized in downstream applications such as the lakes and reservoir monitoring project (Charon Birkett, UMD), forest canopy biomass project (Saatchi et al.), and cloud characteristics monitoring (Steve Palm, GSFC), among many others.

Latent design defects in the flight lasers limited the lifetime of the mission. In order to maximize the time span of data collection, the mission operated for 2 or 3 30-day campaigns per year until 2009. In order to fill the gap between ICESat and ICESat-2 an airborne mission called ICEBridge, which uses multiple instruments including the Airborne Topographic Mapper (ATM) and the Land, Vegetation and Ice Sensor (LViS) instruments, was developed. Through the ICEBridge mission some of the critical ice sheet measurements are being continued. The data from the ICEBridge mission provides a crucial link between the ICESat mission and the ICESat-2 mission, however, does not continuously collect measurements and only provides measurements in targeted areas.

2.2.ICESat-2 Mission

The ICESat-2 mission is the third in the series of decadal survey missions and is slated for launch in 2016. While ICESat-2 will build upon the heritage of the ICESat mission, the new instrument the Advanced Topographic Laser Altimeter System (ATLAS) is a completely different design from the GLAS instrument of the ICESat mission. Two limitations of the GLAS instrument, namely the footprint size and lack of cross track measurements, will be overcome with the ATLAS instrument. First, the footprint (area covered by the laser beam when it contacts the surface) is much smaller with ATLAS providing greater detail about variations in the surface. This improvement will allow the scientists to identify and monitor complex surfaces, such as ice sheets with crevasses, in ways they could not before. Second, the multiple beam laser configuration of ATLAS will give cross track measurements which will enable the determination of the slope (degree of inclination) and aspect (angle of orientation) which allows the scientist to determine the orientation of the feature relative to the sun. These new measurements will greatly enhance the scientific usefulness of the data by providing multi-directional observations for each data point collected. A full description of the ICESat-2 mission and the ATLAS instrument can be found on the ICESat-2 website http://icesat.gsfc.nasa.gov/icesat2/ .

The expanded capabilities of the ATLAS design will provide an opportunity to develop new science and answer questions not possible with the heritage instruments. To assist the mission, and specifically the instrument and product developers, an airborne data simulator called the Multiple Altimeter Beam Experimental Laser (MABEL) has been built. This instrument is currently configured to fly on the high altitude (over 60,000 ft) ER-2 aircraft to simulate ATLAS data but may be re-configured to fly on a more accessible lower flying platform for later flights. MABEL was flying its first science missions on the ER-2 over Greenland and Iceland during the workshop. The initial data from these flights will provide the basis for algorithm development by the SDT. One of the difficulties with creating an algorithm for a new mission is the lack of data before the satellite is on-orbit. The MABEL instrument will enable product developers to have simulated data prior to launch that will be similar in signal response and format to the data anticipated from ATLAS. This will allow products to be made from ATLAS data soon after launch.

3. Identifying the ICESat-2 Community

3.1. Pre-Workshop User Community Review

As a part of the workshop effort, an online questionnaire was prepared and invitations to participate were included in the invitation to the workshop. The purpose of the questionnaire was to gather information on who, at the beginning of the applications work for ICESat-2, is interested in using the data products. A total of 25 respondents are represented in this summary. This section summarizes the results of the responses to date and provides some insight on who the potential users are for ICESat-2 data at the time of the workshop.

Of the 25 respondents, 57% were University employees and 43% work for the Federal government. The majority of the respondents (90%) identified themselves as science data users, who are involved in the creation or analysis of science data products. Only 2 respondents indicated that they are developers or users of applications derived from science data. Figure 1 below shows the respondent's use of ICESat GLAS data.

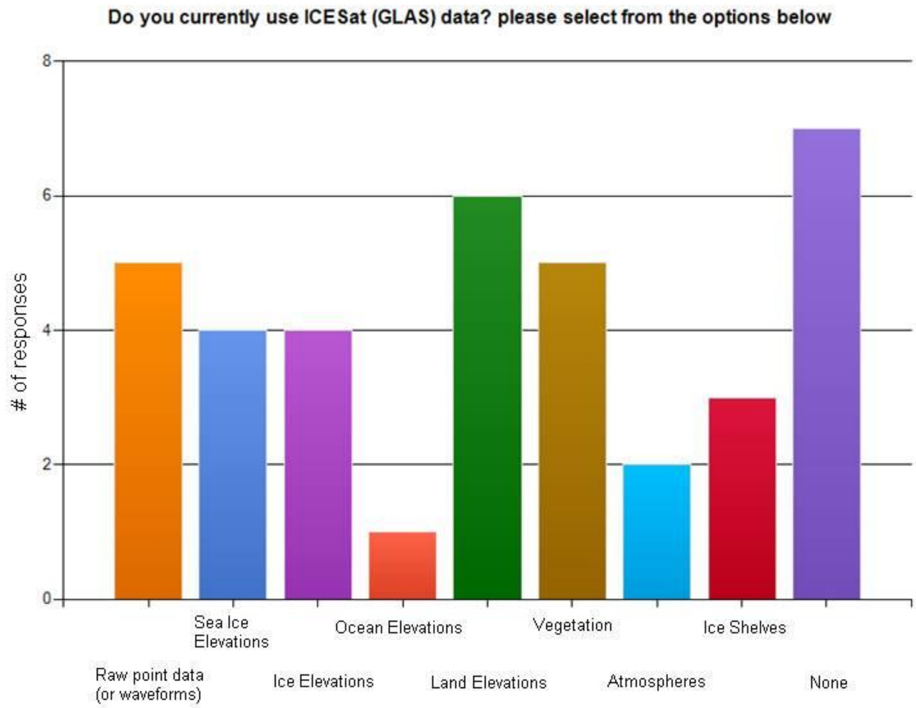

Figure 1 Responses from Question 3 regarding which products from the heritage instrument ICESat GLAS are used.

This figure shows that a broad diversity of products from GLAS are being used by the community, with 32% of respondents reporting that they've never used GLAS data. When asked about the potential products from ICESat-2, respondents also reported a broad interest in data from the different disciplines (Figure 2).

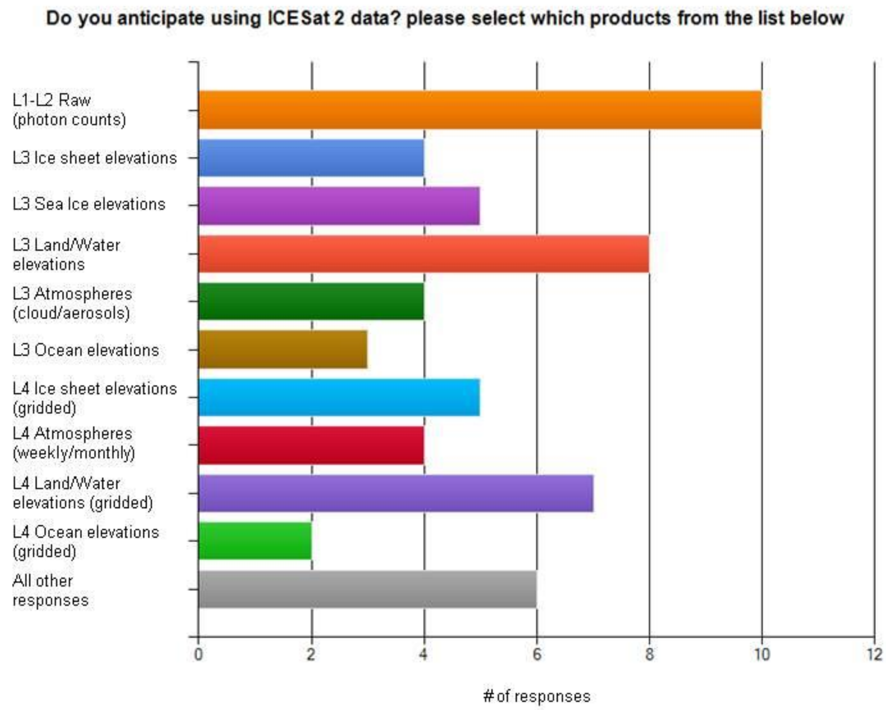

Figure 2 Responses from Question 4 regarding ICESat-2 data products.

Over 57% of the respondents reported that they currently use altimetry products from other sensors. The altimetry products used are small footprint LiDAR, ICEBridge LVIS data, USGS, ASTER, SRTM, National Elevation Dataset (NED), CALIPSO, CryoSat-2, and Aviso data. In addition, several respondents stated that they were actively involved in creating Digital Elevation Models (DEMs) from their own LiDAR instruments, flown on unmanned aerial vehicles and aircraft.

Questions regarding where these datasets were obtained and the data format revealed some interesting responses. 44% of the community stated they downloaded data from the NSIDC DAAC and 25% from other DAACs serving NASA data. 32% of respondents either were product developers or downloaded products directly from the science team website. Only 28% of respondents stated that ICESat-2 data would be more useful if bundled by the data center in a common format and projection with other data on a similar parameter or type. 72% said this would not be useful or increase the value of the data.

When asked about optimal file format, 41% said GeoTiff, 24% HDF and 35% binary data types. 54% of respondents preferred a raster map or 2D array, and a further 27% wanted gap-filled data. Only 20% preferred the 3D array (multiple-observations per location) that typified ICESat data.

Finally, it seemed that most of the respondents were aware of the long latency planned by the ICESat-2 mission before release of the data. 53% of respondents stated that 1 month from acquisition to product delivery is ideal, with the remaining respondents stating 1 week (15%), 1 day (15%) and 12 hours or less (15%). One respondent stated that they were flexible regarding the latency time.

3.2. Workshop Community Feedback (Breakout Sessions)

The direct measurements from ICESat-2 are time of flight photons from which range, elevation and other measurements can be derived. How these measurements are interpreted can tell the user something about the surface that they are measuring. The surface represented can be the actual surface of the Earth or something that is on the surface such as an ice sheet, a building or a tree, it is the interpretation that allows the user to determine what it is that has been measured. To perform this interpretation the user can either calculate the difference between successive ICESat-2 measurements at the same location or compare to ancillary data, such as a DEM or a Digital Terrain Model (DTM), are needed to describe the actual surface of the Earth. The precision of this ancillary information will have a direct impact on the accuracy and precision of the measurements from ICESat-2.

The suite of proposed products for ICESat-2 is shown in the product table in Appendix A of this document. The list of products that will be created for the mission will be finalized as the SDT completes their work and the launch date approaches and will be available to the public from a NASA data distribution center.

The following sections describe the findings of the 3 breakout sessions from the workshop. The breakout sessions were defined based on attendance at the meeting and follow the "theme" areas of the ICESat-2 SDT working groups. The goal of the breakout sessions was to gather information from the users regarding their intended use of ICESat-2 data when it becomes available.

3.2.1. Land Ice and Sea Ice

The land ice and sea ice break out session included the following participants: John DiMarzio, Gretchen Esbensen, Vanessa Escobar, Sinead Farrell, David Gundlach, Ute Herzfeld, Scott Luthcke, Stephen Mango, Leslie Mounteer, Bob Schutz, Nick Steiner, Behnjamin Zib, Jay Zwally.

The primary objectives for the ICESat-2 mission are identified in the level 1 science requirements shown in Appendix E and are driven by the goals to quantify ice sheet and sea ice changes over time. This will be done through repeat measurements from ICESat-2 and by comparing ICESat-2 measurements to heritage measurements from ICESat and airborne campaigns. The change measurements reported in ICESat-2 data products will be used to assess and improve climate, sea level change and ice sheet models while estimating sea-ice thickness to examine ice/ocean/atmosphere exchanges of energy, mass and moisture. The land ice and sea ice products will provide elevation changes over time using the multi-track repeated measurements. Along track and across track measurements will provide slope data that will allow users to calculate the differences in surface height.

ICESat-2 will improve on existing information on land ice dynamics. The mission will produce land ice surface elevation products that enable the determination of ice sheet elevation change rates to an accuracy of less than or equal to 0.4 cm/year on an annual basis. It will also provide information to determine the annual surface elevation change rates on outlet glaciers to an accuracy of less than or equal to 0.25 m/year over areas of 100 km^2 for year-to-year averages. Ice surface products will enable the determination of surface elevation change rate for dynamic ice features that are intersected by its set of repeated ground tracks to an accuracy of less than or equal to 0.4 m/year along 1 km track segments. The ice sheet products will also capture the seasonal changes by measuring the resolution change from winter (accumulation) and summer (ablation) icesheet elevation changes to 10 cm at 25 km X 25 km spatial scale.

The sea ice products will provide monthly surface elevation products to enable when sea surface height references (leads) are available and under clear sky conditions, the sea ice freeboard (floating ice above water's surface) to an uncertainly of less than or equal to 3 cm along 25 km segment for the Arctic and the Southern Oceans; the track spacing should be less than or equal to 35 km at 70º latitude on a monthly basis.

3.2.1.1. Sea Ice

The sea ice community was well represented in this breakout group. There were significant applications discussed for ICESat-2 data products in the areas of land transportation, ocean navigation (both above and under water), rate of melt to identify hazards and model validation and calibrations for climate change, sea level change and rates of melt. The needs of the community as well as the synergistic overlaps with other ICESat-2 potential products, (inland water and snow depth) were discussed at length.

The National Ice Center (NIC) members present during the discussion described themselves as a "central location" for ice data as well as the distribution site for land ice and sea ice products used by NOAA, the US Coast Guard and the Navy. As a user of sea ice data, NIC provides worldwide operational sea ice analyses and forecasts and produces these analyses and forecasts of Arctic, Antarctic, Great Lakes, and Chesapeake Bay ice conditions. ICESat-2 products would be beneficial not only for the navigation of ships and submarines, but also to calculate the melt rate of ice sheets in order to determine navigation hazards such as "downward forming ice poles" that can pierce the top hull of a submarine, along with long term changes such as sea level rise.

Satellite data thus is a key input for the organizations' strategic, tactical and operational data products and ice services to meet the requirements of U. S. government agencies and fulfill U.S. national interests. The use of ICESat-2 data will help calibrate and validate models for navigation products on sea ice and land ice, contribute to sea level data modeling and climate change modeling. Leslie Mounteer indicated the models currently used by NIC would benefit from additional observations for calibration and sea ice map developments that are sent out to users on a monthly basis. Mounteer also stated that NIC would be willing to explore possibilities to create value added products to support the unique needs of their users. The format, size and frequency of the data will not pose a challenge to this community. NIC has the capacity to be an early adopter once the program is implemented into ICESat-2 applications (~3 years from launch). NIC has a broad range of data needs and operates with a broad community of users reduced data latency would be beneficial to this community.

3.2.1.2. Land Ice

A substantial amount of fresh water is stored in ice in the global high latitudes. As this ice grows and subsides there are impacts to both global and local processes. By understanding the changes occurring in the ice in the higher latitudes, there is an opportunity to plan for the coming changes in the mid and lower latitudes where most of the population reside. Although users for land ice data did not have a strong representation at the meeting, users within the break out group (such as National Ice Center) have diverse enough interaction with users like the Department of Defense and the Department of Transportation that they could articulate some product applications for land ice, (such as ice sheet melt rates for inland truck transportation in Alaska). In addition, Stephen Mango stated that NOAA models will benefit from ICESat-2 data by helping to calibrate and validate climate change and ice sheet models, which contribute to NIC products as well as climate change policy.

In addition to ice sheet applications, there was also extensive discussion of the possibility of combining ICESat-2 products with other mission products for water management. Scott Luthcke from the ICESat-2 mission combined the use of ICESat and GRACE data in the past as an application for water resources and hydrology. Mounteer indicated combined data products such as Luthcke's, as well as a snow depth product would be valuable to NIC for permafrost modeling and avalanche hazards. NIC's collaboration with NOAA (Stephen Mango) is unique in the sense that data products distributed by NIC/NOAA are not confined to sea ice and land ice but rather extend to all thematic groups of the ICESat-2 mission.

3.2.1.3. General conclusions of the land ice/sea ice breakout session

The discussion group found four areas where the ICESat- 2 data could bring value to the needs of Sea Ice and Land Ice users: (1) Use the NIC to validate and calibrate NIC models with prelaunch data for ICESat-2 (Possible through an early adopter program). (2) Coordinate field campaigns with Naval, coast guard and submarine units. (3) Combine data for ice melt rates to identify hazards for sea and land navigation transportation. (4) Work with data centers to access and understand the combination of mission data for joint product development (GRACE, ICESat)

3.2.2. Land Elevation and Vegetation

The land elevation/vegetation breakout session included the following participants: Molly Brown, Claudia Carabajal, Leanne Creamer, Michael Lefsky, Lori Magruder, Paul Montesano, Amy Neuenschwander, Macarena Ortiz, Lesley Ott, Woody Turner.

The land elevation products will provide elevation measurements that enable independent determination of global vegetation height within a ground track spacing of less than 2 km over a 2 year period. The land elevation and vegetation products will use measurements from ICESat-2 along with ancillary information to describe features of the Earth as defined in the level 1 science requirements shown in Appendix E. These measurements combined with data from other missions and sources can provide information regarding a range of surface characteristics including canopy height, biomass, volcanic activity, land subsidence and others.

3.2.2.1. Land Elevation

The land/vegetation elevation products from ICESat-2 will significantly contribute to highly precise land DEMs and DTMs, as accurate global ground control from altimetry can help in the production and evaluation of elevation models. Accurate ground elevations are critical to obtaining accurate estimates of various parameters of interest to the ecological community, including vegetation height. There was a lengthy discussion of the current state of DEMs and other ancillary data products that could be used in combination with ICESat-2 data products, and how working with MABEL data as an emulator for ICESat-2 altimetry will contribute to refining algorithms to retrieve accurate ground elevations. Claudia Carabajal and David Harding at GSFC are working with JPL researchers on projects related to the reprocessing of SRTM data including ICESat altimetry ground control, and to correct elevation biases, in the production of an improved elevation model. Similar uses of ICESat-2 altimetry can be expected as the products become available. Accurate global topography data, in a consistent reference frame, is of great interest to the broader community as well. These accurate elevation data will aid Solid Earth and Natural Hazard applications and change studies, and are and will be particularly useful at the higher latitudes, where other topographic control is scarce.

3.2.2.2. Vegetation

Vegetation data products will be derived from the land elevation data as level 3 data products. The vegetation community has requested a number of products and the following products have been proposed for ICESat-2:

- Ground Digital Terrain Model (DTM)
- Canopy height maximum
- Canopy cover
- Decile heights (20, 40, 60, 80% to provide mid-canopy info)
- Surface roughness (250m)

The vegetation community is excited to have a new space-borne LiDAR system that can provide fine resolution measurements for vegetation, but is concerned about the ability of the photon counting LiDAR planned for ICESat-2 to penetrate the canopy of forests. Although ICESat-2 data will have a much higher data density than ICESat data, there will likely only be at most 10 photons per return, due to the sensor design. Hence, deriving the vegetation mid-canopy information needed for biodiversity will require a lot of aggregation both spatially and temporally. The proposed vegetation data products and possible uses for them were discussed at length. In particular, a need for aggregating to higher spatial (250 m) and temporal scales (annual or every two years) to get high quality, precise gridded products. From the discussion, it was clear that users will much prefer high quality, reliable data than low latency, frequent products. In addition, the ICESat-2 data acquisition strategy will enable data acquisition during both leaf-on and leaf-off periods. Another way the vegetation community can exploit the ICESat-2 data is to look at places where the data cross over each other, and calculate change through time. This kind of 'crossover' analysis was widely used with GLAS measurements for ice change analysis early on in the mission. The proposed ICESat-2 vegetation data products will be fine spatial resolution, 25 m resolution along-track, with 2 beam pairs and 30-45 day latency.

In terms data assimilation with existing products, Leslie Ott thought the vegetation data products will be very useful for those trying to characterize biomass variability and land-atmosphere flux, such as Jim Collatz. Currently, NASA Carbon Monitoring System (CMS) models include the 'fast' carbon in leaves and grasses. ICESat-2 will provide information on the 'slow' carbon incorporated in the biomass (woody structure, tree trunks, etc.), which is a substantial unknown in ecosystem models.

There was a discussion about the use of airborne instruments to develop algorithms and to understand how photon counting LiDAR can be used for vegetation work. The MABEL instrument, along with the Slope Imaging Multi-Polarization Photon Counting LiDAR (SIMPL) and other datasets, will provide a range of data for testing the algorithms for biomass and structure and are critical for ensuring functional algorithms at-launch.

3.2.2.3. General conclusions for the land elev. and vegetation breakout session

The primary user community has been identified as the community of modelers interested in vegetation structure as well as those who are tracking sources and sinks of Carbon. These users will be served by the generation of global maps of canopy height, canopy density (percent canopy cover), and surface roughness. Repeat measurements showing the changes in these parameters over the life of the mission (or relative to heritage missions) would also be desirable. Two primary concerns have been raised in the ability of the instrument to resolve high density canopy and in the accuracy of the ancillary data sets needed to create the products. These issues will be investigated by the SDT members as they develop their algorithms for ICESat-2.

3.2.3. Oceans/Inland Water/Atmospheres

The Oceans, Inland Water and Atmospheres breakout session included the following participants: Shyam Bajpai, Charon Birkett, Mark Carroll, Kimberley Casey, Mark Chan, Gennady Chepurin, Raed el-Farhan, David Hancock, Mike Jasinski, Kyle McDonald, Steve Palm, Marouane Temimi, Tim Urban,

The main focus of the ICESat-2 mission is to observe and record measurements in the frozen parts of the world namely ice sheets and sea ice, while providing a global mapping of vegetation height. However, there are significant contributions that can be made by ICESat-2 in the areas of ocean circulation, hydrology and water resources, and atmospheric science. This breakout group had representation from each of these disciplines and discussed the needs of the community as well as the expected capabilities presented earlier by the SDT.

3.2.3.1. Oceans

Oceans cover nearly 2/3 of the Earth's surface. Understanding how they function is a focus of models from General Circulation Models (GCM's) to Ocean Circulation Models. Gennady Chepurin is involved in global ocean assimilation systems. Currently they use altimetry information from Topex and Jason and they are ready to bring in ICESat-2 data as an additional data source to help parameterize the models or alternatively to use as a validation set of observations for model runs. There was some discussion about the use of ICESat-2 in the critical coastal zones but there was not general agreement on what could be done with ICESat-2 data products in this area. Coastal zones and transition zones are of high importance to scientists, resource managers, and in many cases represent territorial boundaries. More interaction with the

SDT algorithm team will be necessary to understand how coastal zones will be treated in all the data products.

3.2.3.2. Inland Water

Inland water interests were represented by approximately half of the attendees in the breakout session. There was interest in both lakes and rivers from operational monitoring perspective as well as overall resource management perspective. ICESat-2 contributions in this area will be significant in lake and reservoir monitoring which feeds in to work that is currently ongoing from Charon Birkett. She indicated that data latency would be a concern for several of her potential customers, including the military. In the case of the USDA Foreign Agricultural Service (FAS) even a single observation of reservoir height can provide crucial indication of the success of a crop in a given region, thus providing an early warning to potential food needs in an area. In addition, she indicated that the laser altimetry will be a validation source for the RADAR altimetry especially over frozen lakes where RADAR may penetrate the ice to some degree. There was discussion about monitoring river stage information to supplement, especially in developing countries where permanent/continuous river gauging equipment is sparse or non-existent. Timely information would be of critical importance here as well. Maurouane Temimi indicated that his group has worked on developing a river ice product to show potential areas of flooding during spring melt due to ice jams. For ICESat-2 this would represent a crossover product between the sea ice and the inland water and created some interest from the product developers (Mike Jasinski, and Tim Urban) as a potentially interesting developmental activity. Lastly, a snow depth product has been proposed for ICESat-2. Potential applications for this product would be snow water equivalent (used for river discharge and water resources management) and avalanche prediction (where snow depth could be coupled with terrain and snow extent from other sources).

3.2.3.3. Atmospheres

The atmospheric science component for ICESat-2 is capable of providing information on a variety of airborne particles from aerosols to clouds and blowing snow. There was discussion of the use of cloud detection capabilities of ICESat-2 as a calibration tool for cloud detection with other missions such as MODIS on Aqua and Terra. A significant area of confusion in cloud detection from visible and thermal sensors is where clouds occur over snow and errors can be as high as 40% or more. These errors represent omission (clouds that occurred but were not represented) as well as commission (features labeled as clouds that were not actually clouds) errors and occur because the detection methods rely on a temperature or albedo difference between the clouds and the ground surface. In the case of snow/ice it is both cold and bright so the methods are not as successful. Mark Chan indicated that if he had coincident measurements from ICESat-2 and MODIS he could calibrate the cloud detection method for MODIS and improve accuracies. Steve Palm explained that the expected orbit for ICESat-2 will result in an overlap with NPP-VIIRS (hard to say if MODIS will still be on orbit when ICESat-2 launches) of approximately 1 month per year in some areas of the poles. Mark Chan believes this may be enough to calibrate the detection methods.

3.2.3.4. General conclusions for the water and atmospheres breakout session

There was general consensus from the group that preliminary data is needed sooner rather than later to allow people to understand what the capabilities of the mission are. This data can come from two fronts the airborne data from the MABEL instrument and from the heritage ICESat instrument. The question was asked whether GLAS data can be used to simulate ICESat-2 data, the SDT members responded "probably yes" however the users of that data would have to be aware that the capabilities of the two instruments are different so caution would need to be taken in the use of that data. The better option is to have higher order products (Level 3 and higher) generated from the MABEL airborne simulator data. The characteristics of this instrument are much more similar to that of ATLAS and would likely give the data users a better feel for the capabilities of actual ICESat-2 data. The current plan for MABEL data collections is not conducive to the generation of inland water products, however if there is strong interest from the community this can be reported to the project science team for further consideration. Lastly there was a strong interest from the entire group in seeing coordination between multiple missions including ICESat-2, SMAP, SWOT, Jason-3, and GRACE-2. There are a number of ongoing missions such as ICEBridge, CARVE and others. How can these missions be leveraged to prepare for ICESat-2? And how can the activities leading up to the ICESat-2 launch be used to support these other projects?

4. Communication Strategies

An important facet of the applications team's work is to engage the community and to broaden the base of users who are aware of the ICESat-2 mission and its capabilities. This is done by holding workshops, but also through participation in meetings that will be attended by communities of interest and by publishing articles in journals and trade publications. The community participates in the following meetings, where they meet their colleagues:

- International Society of Photogrammetry and Remote Sensing (ISPRS) and American Society of Photogrammetry and Remote Sensing (ASPRS) – altimetry and elevation sessions
- American Association of Geographers(AAG) – organized sessions, USGS attends the AAG for free so they attend in large numbers
- Ecological Society of America (ESA) annual meetings
- American Geophysical Union (AGU) (Fall)

The journals listed below were suggested by attendees at the workshop as pertinent to their work and are likely to be viewed by their peers:

- International Society for Optics and Photonics (SPIE) journals
- Photogrammetric Engineering and Remote Sensing
- Earth Observing Systems transactions
- Geophysical Research Letters
- Water Resources Research

The applications team will engage communities via the above listed meetings and through journal articles and white papers (such as this report).

5. Conclusions and Action Items

The overarching goal of the ICESat-2 mission applications team is to identify existing and potential applications that can utilize ICESat-2 data products and engage them in the mission during the pre-launch period so that the products generated will meet the needs of the broader community in addition to the primary science users. This workshop and the survey have provided a valuable first step by collecting information regarding the communities that are currently aware of ICESat-2 and are already engaged in the process. This was the first effort to understand the user community for this mission. Some concern was raised regarding the enormous amount of data that photon-counting instruments (like MABEL and ICESat-2) will create, and how to bring users into the process of understanding this information. Feedback from both the SDT and the users has been positive with both groups indicating that they were unaware of the capabilities of the other. Moving forward, it is clear that the applications team will need to work to encourage involvement from more true applications users. Applications from the heritage mission, ICESat, have been difficult to identify and there may be few to build from. One possible reason for this is the technical nature of the lower level (L2 and lower) data requires a substantial understanding of not just the instrument measurements but also of the needed ancillary data sets. It is probable that applications will come from the Level 3 and 4 products or perhaps have been created as third tier results where the metrics are not captured at the DAACs. The applications team will work to clarify the path to applications for ICESat-2 such that if applications are created from derived products it will be traceable. To accomplish this, the following action items have been identified:

1) Broad distribution of workshop report to engage community of potential that has already been identified but was not in attendance.
2) Broader distribution of survey invitation to engage additional potential applications users.
3) Develop applications plan.
4) Develop applications traceability matrix.
5) Engage the Science Definition Team to identify additional potential applications.
6) Develop an Early Adopter program for ICESat-2.

This also means the work for applications (identifying applications and identify users that can make, convert and distribute data products) will be highly valued. Additional questionnaires may be used during the pre-launch phase of applications work to determine whether the goal of information dissemination is being achieved.

6. Appendices

Appendix A: ICESat-2 Proposed Products Table

Product Number	Product Name	Processing Level	Frequency
0	Telemetry Data	L0	Files for each APID for some defined period
1	Reformatted Telemetry	L1A	Uniform time TBD (minutes)
2	Science Unit Converted Telemetry	L1B	Uniform time TBD (minutes)
3	Global Geolocated Photon Data	L2A	Uniform time TBD (minutes)
4	Calibrated Backscatter Profiles	L2A	Per orbit
5	Photon Elevation Histograms	L2B	Uniform time TBD (minutes)
6	Antarctica/Greenland Ice Sheet Elevation	L3	Files per ice sheet per orbit
7	Arctic/Antarctic Sea Ice Elevation	L3	Files for each pole per orbit
8	Land/Water/Vegetation Elevation	L3	Files per half orbit
9	ATLAS Atmosphere Cloud Layer Characteristics	L3	Per day
10	Arctic/Antarctic Sea Ice Freeboard	L3	Files for each polar region per orbit
11	Antarctica/Greenland Ice Sheet H(t) Series	L3	Files for each ice sheet per year
12	Ocean Elevation	L3	Files per half orbit
13	Inland Water Elevation	L3	Per day
14	Antarctica/Greenland Ice Sheet H(t) Gridded	L4	Per ice sheet per year
15	Antarctica/Greenland Ice Sheet dh/dt Gridded	L4	Per ice sheet per mission year
16	ATLAS Atmosphere Weekly	L4	Per polar region Gridded 2x2 deg. Weekly
17	ATLAS Atmosphere Monthly	L4	Per polar region Gridded 1x1 deg. Monthly
18	Land/Canopy Gridded	L4	Annual at coarse resolution (0.5 deg. Tiles)
19	Ocean MSS	L4	Monthly
20	Arctic/Antarctic Gridded Sea Ice Freeboard	L4	Aggregate for entire month for each polar region
21	Arctic/Antarctic Gridded Sea Surface Height w/in Sea Ice	L4	Aggregate for entire month for each polar region

Appendix B: Agenda

Ice, Cloud, and Land Elevation Satellite (ICESat-2) Applications Workshop

April 12, 2012

Location: NASA/GSFC Building 32 Room E103/109

The ICESat-2 project will implement a space-borne mission designed to collect altimetric measurements of the Earth's surface, optimized to measure the heights and freeboard of polar ice and global vegetation canopy. Goals of applications group: Improve communication between scientist and user community Increase collaboration opportunities with user groups by identifying the challenges and needs Expected Workshop Outcome: Develop Applications traceability matrix (link potential applications to planned ICESat-2 products), create support for planned ICESat-2 data products, and identify potential products that are currently not planned but would be of value to the community.		
12 April Thursday		
8:00am	**Registration and Coffee**	
8:30am	Shahid Habib, NASA *(10 min)*	Workshop Welcome
8:40am	Woody Turner/Tom Wagner, NASA HQ *(15 min)*	ICESat-2 Welcome, Charge to Workshop
8:55am	Molly Brown, NASA *(15 min)*	ICESat-2 Applications Requirements and strategy
9:10am	Thorsten Markus, NASA *(15 min)*	ICESat-2 Mission Overview
9:25am	Bill Cook, NASA (*15 min*)	MABEL Atlas simulator
9:40am	Claudia Carabajal, NASA (Sigma Space) *(15 min)*	ICESat Heritage measurements and data products with lessons learned
9:55am	Marilyn Kaminski, NSIDC DAAC *(15 min)*	Current applications/users for ICESat (GLAS), Ice-bridge and cryo products from the NSIDC DAAC
10:10 to 10:30am	**Morning Break** Please use this opportunity to fill out surveys if you haven't already done so	
PART 1: Invited presentations that provide a brief description of anticipated mission products and their potential applications (15 minutes per product)		
	Product Category	Potential Client/User

10:30- 10:45am	Ice Sheet/Mass Balance Jay Zwally	NOAA, NCAR
10:45- 11:00am	Sea Ice Sinead Farrell	Navigation, NIC (Coastguard, Navy and civilian), ESA
11:00- 11:15am	Land Elevation/Vegetation Michael Lefsky	Canopy Height, biomass and Carbon
11:15- 11:30am	Ocean Elevation Tim Urban	Coastal City planning, storm surges, public Health
11:30- 11:45pm	Inland Water Michael Jasinski	Lake elevation, snow depth, water resources
11:45- 12:00pm	Atmospheres Steve Palm	Clouds and Aerosols, Modeling, Air traffic control, flux atmospheric studies
12:00- 1:30pm	LUNCH (Building 33 Jack's Café or NASA Cafeteria Building 34) Please use this opportunity to fill out survey	
Part 2Breakout Sessions in three thematic application groups (Ice, Oceans, Land applications) • Charge to the breakout groups o Identify primary applications, institutions, and organizations within thematic areas that could benefit from ICESat-2 measurements • Provide quantitative information to the mission as the basis for the missions application program		
1:30- 3:30pm	Break Out Groups B32 E103; B32 E109; B33 H118	
3:30- 4:15	5 minute informal (no presentation) summaries from each breakout group lead Discussion of entire group	
4:15- 4:30	Closing remarks: Molly Brown, Thorsten Markus	
4:30pm	**Workshop Adjourned**	

Appendix C: List of Attendees

Amy Neuenschwander	UT-Austin
Angela Ottoson	NOAA-NIC
Augusto Getirana	NASA
Bea Csatho	Buffalo
Benjamin Morgan	USCG Navigation
Behnjamin Zib	NOAA-NIC
Charles Webb	NASA
Charon Birkett	UMD
CK Shum	OSU
Claudia Carabajal	NASA
Dalia Kirschbaum	NASA
David Gundlach	NOAA-NIC
David Hancock	NASA
David Harding	NASA
Doug Morton	NASA
Douglas Jackson	USCG Navigation
Elizabeth Hoy	UMD
Geir Moholdt	Scripps
Gennady Chepurin	UMD
Gretchen Esbensen	NOAA-NIC
Guoqing Sun	UMD
Jack Saba	NASA
James Foster	NASA
Jay Zwally	NASA
John DiMarzio	NASA
Hahn Chul Jung	NASA
Karen Mohr	NASA
Kimberly Casey	NASA
Kyle McDonald	NASA
Leanne Creamer	NASA
Lesley Ott	NASA
Leslie Mounteer	NOAA-NIC
Lori Magruder	UT-Austin
Macarena Ortiz	CUNY
Marilyn Kaminski	NSIDC
Mark Carroll	NASA
Marouane Temimi	CUNY

Michael Lefsky	Colorado State
Mike Jasinski	NASA
Molly Brown	NASA
Nick Steiner	CUNY
Paul Montesano	NASA
Raed el-Farhan	The Louis Berger Group
Robert Schutz	UT-Austin
Scott Luthcke	NASA
Shyam Bajpai	NOAA-operations
Sinead Farrell	NASA
Stephen Mango	NOAA-NESDIS
Steve Palm	NASA
Thomas Wagner	NASA
Thorsten Markus	NASA
Tim Urban	UT-Austin
Ute Herzfeld	UC-Boulder
Vanessa Escobar	NASA
William Cook	NASA
Woody Turner	NASA
Yuekui Yang	NASA

Table 1 List of attendees.

Appendix D: Questions on ICESat-2 Applications Questionnaire

1. What type of institution do you work for?

University

Federal Government

State/Local Government

NGO (non-governmental organization)

Private Industry

2. How would you characterize your data use?

Science Data User (creation or analysis of science data products)

Applications Developer (create decision products)

Applications User (consumer of decision products)

Other (please specify)

3. Do you currently use ICESat (GLAS) data? please select from the options below

Raw point data (or waveforms)

Sea Ice

Ice Elevations

Ocean Elevations

Land Elevations

Vegetation

Atmospheres

Ice Shelves

None

4. Do you anticipate using ICESat 2 data? please select which products from the list below

L1 - L2 Raw (photon counts, backscatter, telemetry)

L3 Ice Sheet elevations

L3 Sea Ice

L3 Land/water elevations

L3 Atmospheres (cloud, aerosols)

L3 Ocean elevations

L4 Ice Sheets (gidded)

L4 Atmospheres (weekly or monthly)

L4 Land/water elevations (gridded)

L4 Ocean elevations (gridded)

L4 Lake elevations

L4 Snow depth

None

Other (please specify)

5. Do you use other altimetry products?

Yes

No

6. If yes, which ones?

7. From where do you usually download your data?

NSIDC DAAC

Product Developer

Science Team Website

Other DAAC (NASA Distributed Active Archive Center)

Other (please specify)

8. What would be the ideal format for you to receive data?

	File Type	***Projection***	***Data Structure***
Data Format	Geotiff, HDF, Binary	Polar Stereographic, Lambert Azimuthal, Azimuthal Equidistant, EASE Grid	2D array (points or raster map), 2D array (gap filled), 3D array (multi-observations per location)

9. What is your ideal lag time from data acquisition to product delivery?

3 hours

12 hours

1 day

1 week

1 month

Other (please specify)

10. Would ICESat-2 data be more useful to you if it were bundled by the data center (in common format and projection) with other data (from other missions or ground data)?

Yes

No

11. If yes, which products?

Appendix E: ICESat-2 Level 1 Science Requirements

4.1 Science Requirements

The science objectives in Section 2.1 can be achieved in total or in part via the baseline or threshold science mission requirements listed here respectively. The baseline mission provides substantially more value to NASA and the Earth science community.

4.1.1 Baseline Science Requirements

a) ICESat-2 shall produce an ice surface elevation product that enables determination of ice-sheet elevation change rates to an accuracy of less than or equal to 0.4 cm/yr on an annual basis.

b) ICESat-2 shall produce an ice surface elevation product that enables determination of annual surface elevation change rates on outlet glaciers to an accuracy of less than or equal to 0.25 m/yr over areas of 100 km^2 for year-to-year averages.

c) ICESat-2 shall produce an ice surface elevation product that enables determination of surface elevation change rates for dynamic ice features that are intersected by its set of repeated ground-tracks to an accuracy of less than or equal to 0.4 m/yr along 1-km track segments.

d) ICESat-2 shall produce an ice surface elevation product that enables resolution of winter (accumulation) and summer (ablation) ice-sheet elevation change to 10 cm at 25-km x 25-km spatial scales.

e) ICESat-2 shall provide monthly surface elevation products to enable, when sea surface height references (leads) are available and under clear sky conditions, the determination of sea-ice freeboard to an uncertainty of less than or equal to 3 cm along 25-km segments for the Arctic and Southern Oceans; the track spacing should be less than or equal to 35 km at 70 degrees latitude on a monthly basis.

f) ICESat-2 shall make measurements that span a minimum of three years.

g) ICESat-2 shall produce an ice surface elevation product that, in conjunction with ICESat-1, enables determination of elevation changes on a decadal time scale.

h) ICESat-2 shall produce elevation measurements that enable determination of global vegetation height to within 3-m accuracy at 1-km spatial resolution in vegetated areas with canopy closures less than or equal to 75 percent under clear sky conditions (TBR).[1]

---

[1] Development of a vegetation height model with 1-m accuracy at 1-ha resolution has been identified as a science requirement by the ecosystem structure research community. ICESat-2 will not achieve the vegetation science objectives but rather will support them to the extent possible without compromising ice science objectives. Results from the ICESat-1 mission suggest that ICESat-2 will be capable of producing a height surface with 3-m accuracy at 1-km spatial resolution assuming that off-nadir pointing can be used to increase the spatial distribution of observations over terrestrial surfaces.

i) The ICESat-2 Project shall conduct a calibration and validation program to verify delivered data meet the requirements in 4.1.1 a, b, c, d, e, g and h.

4.1.2 Threshold Science Requirements

a) ICESat-2 shall produce an ice surface elevation product that enables determination of ice sheet elevation change rates to an accuracy of less than or equal to 2 cm/yr on an annual basis.

b) ICESat-2 shall produce an ice surface elevation product that enables determination of annual surface change rates of outlet glaciers to an accuracy of better than 0.50 m/yr over areas of 100 km^2 for year-to-year averages.

c) ICESat-2 shall produce an ice surface elevation product that enables determination of surface elevation change rates for dynamic ice features that are intersected by its set of repeated ground-tracks to an accuracy of less than or equal to 0.8 m/yr along 1-km track segments.

d) ICEsat-2 shall produce an ice surface elevation product that enables resolution of winter (accumulation) and summer (ablation) ice-sheet elevation change over slopes less than 1° to 5 cm at 25-km x 25-km spatial scales.

e) ICESat-2 shall provide monthly surface elevation products to enable, when sea surface height references (leads) are available and under clear sky conditions, the determination of sea-ice freeboard to an uncertainty of less than or equal to 3 cm along 50-km segments for the Arctic and Southern Oceans; the track spacing should be less than or equal to 35 km at 70 degrees latitude on a monthly basis.

f) ICESat-2 shall make surface elevation measurements over ice sheets and sea ice for no less than a 3-year duration for at least 182 days each year to provide seasonal sampling.

g) The ICESat-2 Project shall conduct a calibration and validation program to verify data delivered meets the requirements in 4.1.2 a, b, c, d, and e.

4.1.3 Mission Success Criteria

The ICESat-2 Mission will be considered successful if it:

a) Launches into a near-polar orbit that provides near-global coverage of ice sheet elevation change and sea ice freeboard data products (TBR).

b) Produces space-based calibrated and validated ice elevation products that meet the Threshold Science Requirements (Section 4.1.2) (TBR).

c) Records, calibrates, validates, publishes, and archives science data records and calibrated geophysical data products in a NASA DAAC for use by the scientific community (Section 4.5).

4.1.4 Science Instrument Requirements

The ICESat-2 instrument shall be a micro-pulse, multi-beam lidar.