Ice, Cloud and land Elevation Satellite-2 2nd Applications Workshop

March 10 and 11, 2015
Goddard Visitor Center, NASA Goddard Space Flight Center
Greenbelt, MD 20771

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During the pre-launch phases of the ICESat-2 mission (through Phase D), the ICESat-2 Applications Team (Table 1) engages ICESat-2 end users and builds broad support for ICESat-2 applications through a transparent and inclusive process. The ICESat-2 Applications Coordinator designs and executes the pre-launch activities in coordination with the ICESat-2 Project Science Office. The ICESat-2 Project Science Office and ICESat-2 Science Definition Team provide support and guidance to the ICESat-2 Applications Coordinator for the proposed activities. NASA Headquarters is a valued partner in the Applications efforts providing guidance on how to propagate the program to other ESD missions. This document has been drafted in support of the ICESat-2 pre-launch activities and with guidance by the ICESat-2 Deputy Project Scientist, ICESat-2 Science Team Applications Liaison and NASA Headquarters Applied Sciences Representative.

Table 1. ICESat-2 Applications Team Members as of June 2015

Role in ICESat-2 Mission	Members	Affiliation
ICESat-2 Deputy Project Administrator (DPA)	Vanessa Escobar	NASA's Goddard Space Flight Center (GSFC)/SSAI
ICESat-2 Applications Coordinator	Sabrina Delgado Arias	GSFC/SSAI
ICESat-2 Program Applications Lead	Molly Brown	University of Maryland
ICESat-2 Science Team Applications Liaison	Mike Jasinski	GSFC
ICESat-2 Deputy Project Scientist	Tom Neumann	GSFC
ICESat-2 Science Team Leader	Lori Magruder	University of Texas
NASA Headquarters Applied Sciences Representative	Woody Turner	NASA Headquarters (HQ)

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1 Introduction

1.1 ICESat-2 Mission Applications

The first generation Ice, Cloud and land Elevation Satellite (ICESat) provided the world with unprecedented accuracy for measuring the vertical distribution of the Earth's surface and atmosphere. ICESat's measurements have enabled major advances in a range of interdisciplinary applications and helped inform critical decisions, including determining the safest path for vessels navigating in the Arctic and establishing future changes in Arctic shipping potential. The second generation ICESat-2 Mission, due to be launched in 2017, will offer one of the most spatially dense and fine precision instruments for global measurement of the earth's surface elevation. This document reports on the mission's second applications workshop, held on March, 2015 in Greenbelt, MD.

The objective of the Applications Program is to provide a framework for building a broad and well-defined user community for ICESat-2 during the prelaunch phases of the mission to maximize the use of data products after launch. The focus of the ICESat-2 Applications Team—the current membership of which is listed in **Table 1**—is to explore the advantages of the photon-counting approach, by working with the users to identify opportunities for using the new measurements in specific applications. Mission Applications provide insight into the range of potential uses of new satellite observations and helps communicate the value and impact of mission products. The application activities facilitate collaboration with broad communities of data users involved in the following areas of interest to the Mission: ice sheets, sea ice, vegetation, atmosphere, inland water, and oceans. These thematic areas are intentionally chosen to correlate with the science objectives of ICESat-2 and are intended to help the people involved in the mission better understand the potential utility of the mission's data and foster innovative use of the measurements to inform actionable decisions that are relevant and of value to society.

The central element of the ICESat-2 Applications Program is communication and engagement used to discover and demonstrate innovative uses and practical benefits of ICESat-2. The first workshop for the mission was held at the Goddard Space Flight Center (GSFC) on April 12, 2012 and brought together a community of users to explore jointly the mission plans for using ICESat-2 measurements. The report and action items of the first workshop can be found here:
http://icesat.gsfc.nasa.gov/icesat2/applications/ICESat2_Applications_Workshop1_Report_final.pdf

Building on the success of the first workshop, the ICESat-2 Applications Team hosted its Second Applications Workshop (the subject of this report) at the GSFC Visitor Center in Greenbelt, MD, on March 10-11, 2015. The event was held at GSFC in Greenbelt, Maryland, on March 10-11, 2015. The workshop identified measurement requirements for various application concepts of interest that leverage the mission science objectives. The workshop agenda and list of participants are included as part of the appendices in this report, as well as in the event page created for the workshop: http://events.SignUp4.com/ICESat-2Workshop. All workshop presentations are also posted in the event page. The agenda for the event can be found in Appendix F.

This report was compiled by the ICESat-2 Applications Team and reflects the discussions and information gathered at the workshop. The report was sent to Mission Project members and NASA Headquarters (HQ) for review and comments. The final report represents the results of the workshop, the feedback from the user community and responses from the ICESat-2 Mission and NASA HQ.

2 Workshop Description

2.1 Purpose and Goals

The motivation for the 2nd Applications Workshop was to bring together the Mission Project Science Office and Science Definition Team members with potential users of the ICESat-2 data and discuss the functionality and potential applications for the mission data products. The workshop served as a venue for building an interdisciplinary dialogue on how the mission products could potentially be integrated into various applications that will inform activities and decisions of interest to the people convened, including people from universities, government agencies, and the commercial and private sectors.

The goals for the workshop were:

- Provide an overview of the ICESat-2 Mission and its planned data products
- Define critical needs shared by the different communities present
- Identify potential applications for the planned ICESat-2 data products and potential products of value to the community not currently planned by the Mission
- Foster the development of new collaborations

2.2 Meeting Framework

In preparation for the meeting, the ICESat-2 Applications Team sent out an online questionnaire soliciting information on current use and needs for remote sensing data. The online questionnaire was also sent out to the broader ICESat-2 community after the workshop. A final report of the complete questionnaire will be reported to the mission in October. There was also a mission Applications Traceability Matrix (ATM) distributed in the meeting packets for all attendees. An ATM is a document that provides an overview of what the mission will potentially accomplish relative to an end-user decision-making-activity objective suggested through community engagement. The ATM contains the necessary high-level information needed to understand the extent to which ICESat-2 measurements can inform a particular decision. The ATM was used during this meeting as a template for discussion and to help in identifying application concepts that could benefit from the ICESat-2 measurements described by the Mission. The ATM can be found in Appendix C.

The workshop brought together a total of 52 participants for both days with expertise in sea ice, agriculture, coastal hazards, food security, snow hydrology, volcanology, communications, education, biomass estimation, floods/droughts forecasting, seismic hazards, among other fields. The meeting leveraged the range of knowledge present to explore the diverse interests for a broadening of the use of ICESat-2 data products.

2.2.1 Day one

The first day of the event focused on providing a thorough description of the ICESat-2 Mission, the mission products, the Distributed Active Archive Center and the mission Applications Program. Three ICESat-2 Early Adopters were also invited to present their pre-launch research to the audience. The Early Adopter (EA) presentations were done jointly with their selected end user. Together the EA and the end user discussed how the research being conducted by the EA was being integrated into the end user's decision or policy framework. The EA talks focused on: (1) the use of sea ice products for navigation applications in the Arctic presented by Angela

Ottoson, (2) applying the inland water product for Global Flooding Partnerships (GFP) presented by Guy Schumann and; (3) operational water level monitoring for lakes and reservoirs presented by Charon Birkett.

Break-out sessions for Day one were chaired by a Mission Project Science Office or Science Definition Team member. The breakout sessions corresponded to applications for different land cover types: 1) Sea Ice & Open Ocean, 2) Hydrology, and 3) Vegetation & Glaciology. The break out group attendance showed a higher number of participants interested in Sea Ice and Vegetation applications compared to Hydrology, Glaciology and Atmosphere[1]. The information collected in the breakout session groups reflects this asymmetry of interests, with no application concepts developed for atmosphere. Additional work will be necessary to identify underrepresented applications for the Mission, as well as to expand the potential users in hydrology, glaciology, and atmosphere.

2.2.2 Day Two

The second day of the workshop was used for discussion and for expanding on questions and comments from Day one. An overview of the breakouts was also presented and used as a discussion platform for the closing panel. Three guest speakers on the panel encouraged the audience to engage in needed dialogue on potential applications of ICESat-2 data for seismic hazards, the coastal zone, as well as to develop technologies that enhance collaboration. There were also recommendations for advertising future calibration and validation campaigns for ICESat-2 so that users with interests in the planned areas could leverage the campaign and better sync their research to the data available from the ICESat-2 airborne simulator or MABEL (Multiple Altimeter Beam Experimental Lidar). Suggestions were also made for future meetings to leverage the work of Jason and OSTM/Jason 2 satellite altimetry mission data.

2.3 Outcomes

The ICESat-2 Applications workshop allowed for discussion of increased collaboration opportunities with user groups to promote support for the planned ICESat-2 data products. The event also showcased existing research efforts from the ICESat-2 Early Adopter Program to help demonstrate the use and applications of the mission products in decision support scenarios. The Early Adopters proposed ways of applying the ICESat-2 data to their specific applications. A synthesis of the work being carried out by the Early Adopters at the U.S. Naval Research Laboratory, the Joint Institute for Regional Earth System Science & Engineering, and the Earth System Science Interdisciplinary Center is provided in Table 1.

This report explains the goal of the applications program and how the ICESat-2 Early Adopters help leverage the effort. A summary of presentations given by the Mission, NSIDC DAAC, Early Adopters, and guest speakers can be found in Sections 3 and 4. The results of the meeting have provided the ICESat-2 mission a better understanding of how mission products may be used and also highlight challenges and current knowledge data gaps across various disciplines.

This report also provides a list of questions and responses discussed during the workshop that address the mission and end user needs (found in Appendix A). These questions were circulated within the ICESat-2 Project to provide feedback to the mission and provide an improved

[1] In the year prior to the workshop the Applications Team conducted a Joint Vegetation Tutorial with Landsat 8 and a Sea Ice Focus session, which may explain the higher number of participants interested in these areas.

understanding of the range of applications and policy questions that help support ICESat-2 and leverage the use of science in societally relevant applications.

3 ICESat-2 Mission

3.1 Mission Overview & Updates

ICESat-2 is scheduled to launch in October 2017 using a Delta II rocket launched from Vandenberg Air Force Base. The instrument is currently in Integration & Test (I&T) and delivery to spacecraft is planned for summer 2016. The processing of the ICESat-2 data will be done at Goddard Space Flight Center and data products will be distributed to the public via the National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC) in Boulder, Colorado.

ICESat-2 has four science objectives for ice sheets, sea ice and vegetation, which drive the Mission design:

- Quantify polar ice-sheet contributions to current and recent sea-level change and the linkages to climate conditions.
- Quantify regional signatures of ice-sheets to assess mechanisms driving those changes and improve predictive ice sheet models; this includes quantifying the regional evolution of ice sheet change, such as how changes at outlet glacier termini propagate inward.
- Estimate sea-ice thickness to examine ice/ocean/atmosphere exchanges of energy, mass and moisture.
- Measure vegetation canopy height as a basis for estimating large-scale biomass and biomass change.

The Mission is interested in knowing how as a whole ice-sheets are changing (losing/gaining mass). It is known that the biggest changes are around the margins of the continent, while the interior is relatively stable. ICESat-2 measurements of regional signatures will provide better quantification of how ice-sheets are changing as a whole and provide improved measurements over the Arctic glaciers or sloped areas.

Another big design driver for ICESat-2 is sea ice. Very high precision and timing requirements are needed for the retrieval of sea ice thickness. ICESat-2 will generate monthly maps of sea ice thickness. In general, the retrieval of sea ice thickness will consist of measuring the elevation of freeboard (portion above sea level) and the open water or lead in between. Sea surface height will be measured with very high precision at 3cm. The difference between sea surface height and the height of ice will be taken to calculate freeboard. Knowledge of the densities of water and ice will allow for extraction of sea ice thickness assuming buoyancy and accounting for snow cover.

The new photon counting approach used in ICESat-2 will offer a huge degree of freedom in how data is analyzed. Data can be accumulated over various distances and staked for roughness analysis at different scales. With ICESat-2 a single photon is measured with a precision of approximately 30 centimeters and actual precision is determined by accumulating several photons. More data will provide the ability to look at shorter distances. The elevation uncertainty is directly linked to geolocation and surface slope, which reduces the geolocation error. ICEat-2 has a geolocation knowledge requirement of 6.5 m.

ICESat-2 extracts elevation change on an orbit to orbit basis using six pairs of beams to interpolate the reference ground track in every orbit. Thus, ICESat-2 will determine slope on a seasonal and annual basis. ICESat-2's six beams are organized into a 3x2 array, with each pair separated by 90 m and consisting of both weak and strong beams. Each beam is expected to illuminate a spot approximately 14 m in diameter. This allows ICESat-2 to resolve leads or small areas of open water. ICESat-2 will also have a Pulse Repetition Frequency (PRF) of 10 kHz or 1 measurement every 70 cm. In comparison, the first generation ICESat satellite took a measurement every 167 meters and had a footprint of 70 meters.

ICESat-2 will also provide much more extensive and denser coverage with a 91-day repeat orbit, inspired by ICESat-2's seasonal ice-sheet requirement, and 92-degree inclination. Every 91 days or season ICESat-2 will go over the same exact area. While there will be big gaps in the data when going over south tropical latitudes, ICESat-2 will operate with repeat track mode over Arctic regions and with systematic off-pointing over mid-latitudes to increase data density and optimize coverage over land. ICESat-2 will go up to 88 degrees north and south.

The *Advanced Topographic Laser Altimeter System* (*ATLAS*) is ICESat-2's sole instrument. While ice-sheets and sea ice are a big design driver for its design, vegetation is not; however, it impacts spacecraft operations and data volume. The signal over vegetation will be more diffused as the laser goes through the trees. Tree type, coverage, canopy density are some of the factors that will affect the signal. Other operational products will include: atmospheric profiles, ocean heights and inland water (river, lake) heights. More about ATLAS and the ICESat-2 mission measurements and design can be found at: http://icesat.gsfc.nasa.gov/icesat2/instrument.php

3.2 Data Product Plan

Tom Neumann, Deputy Project Scientist for ICESat-2, provided an overview of what the data will look like for different surface data types and discussed the expected data product schedules, volumes and latencies. ICESat-2 will provide 20 products with latencies ranging by data level, as follows: Level-0: 8 times per day, L1: 2 days, L2: 21 days, L3 (ATL06-ATL10): 45 days, and L3 (ATL11-ATL20): 45 days from last data in product. Below is a description of the Mission Product concept. The mission product table can be found in Appendix E.

The ICESat-2 Data Product Plan is a group effort led by both the Project Science Team and the Science Definition Team (SDT). The project science office is coordinating primarily the lower level data products including the Level 1B data product, which consists of instrument corrections. The SDT is responsible for all ICESat-2 science data products.

Level 2A/ATL03 data product combines the Level 1B product with pointing and orbit determination. It is a geolocated photon cloud that provides longitude, latitude, and height of every photon event that is downlinked from the satellite. This data product is an along-track product and contains the classification of each photon (signal photon versus background/noise photon), as well as a flag for surface type (e.g. sea ice, ocean, or land ice). The Mission expects that the Level 2A/ATL03 data product is the lowest product end-users will be interested in.

The SDT led data products are higher level data products organized by surface type: ice sheet, sea ice, land, ocean, atmosphere, and inland water. They contain various parameters of interest to the respective communities for each land type. L3A products are along-track products. L3B products are derived from L3A products (ATL11 onwards) thereby building a time series of change. Time series or gridded products combine a lot of spatial information over a time period.

Overall, the Science Team is looking for change or repeat tracks over polar areas and for coverage or mapping over mid-latitudes via off-pointing. Over oceans, ICESat-2 will be mostly in repeat track mode to minimize the off-nadir angle of the satellite with respect to the ocean surface. The off-nadir plan order is not finalized. During the first 91 days, ICESat-2 will be pointing nadir mode. Pointing beyond the second repeat, is still under discussion. As with ICESat, target of interest requests for study sites of interest will also be possible for the ICESat-2 Mission. Plans for where the satellite will be pointing on a specific day will be made available prior to launch via the project website (http://icesat.gsfc.nasa.gov/icesat2/) or via a pointing request website that will be linked to the project website and made active approximately 3 months prior to launch.

Much of the data latency will be due to the time needed to get precise GPS ephemeris to do the final solution on pointing and orbit determination to get geolocation uncertainty down to the 6.5m level. Initial actual data will be available 45 days after acquisition on orbit, but timing depends on what level of data a person is interested in: initial and rapid level 2 data products will be available approximately 4 days after downlinking or about 5 days after data collection; however, at that point, the data photons in these products will have larger error bars on longitude, latitude and height and no precise orbits.

3.3 Pre-launch data for ICESat-2

Mike Jasinski, Science Definition Team member and Applications Liaison to the Mission, provided an overview of Multiple Altimeter Beam Airborne Lidar (MABEL) and simulated ATLAS data (MATLAS). The discussion included an overview of the MABEL instrument, algorithm development and examples for the sea ice, vegetation, and inland water land surface types.

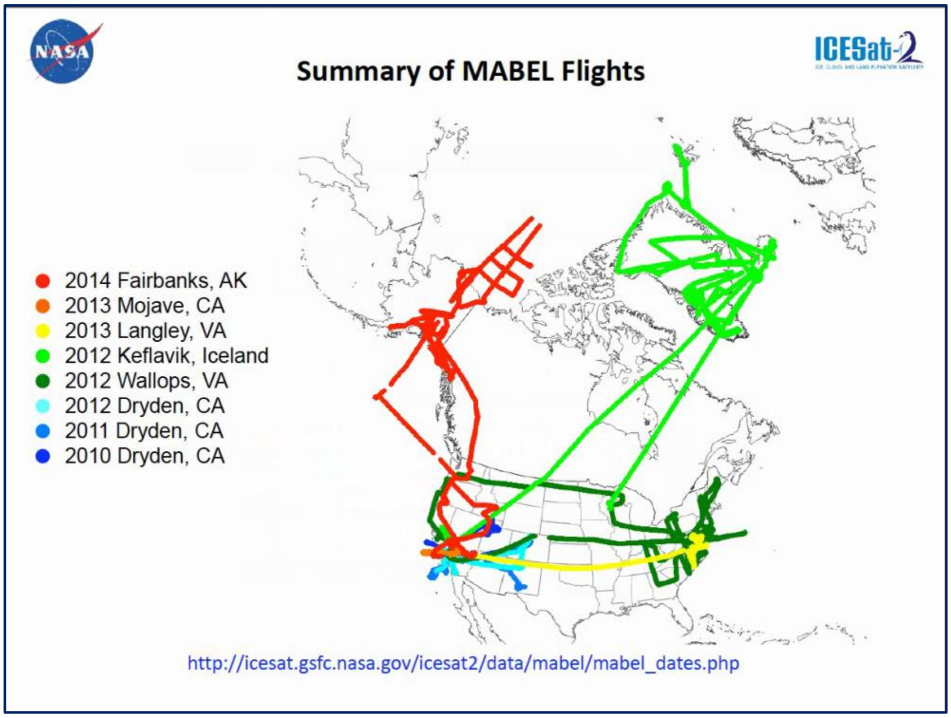
3.3.1 MABEL Data

MABEL was built at GSFC and is designed as a prototype for the ICESat-2 ATLAS instrument. MABEL data are currently being used as prelaunch data for the mission applications and the ICESat-2 Early Adopter Program. More details on MABEL can be found on the mission website: http://icesat.gsfc.nasa.gov/icesat2/data/mabel/mabel_docs.php

The goals for the MABEL data are to:

1) Validate the ICESat-2 models that are used to predict ATLAS instrument performance,
2) Evaluate the ICESat-2 photon counting (532 nm) measurement concept,
3) Be used to develop retrieval algorithms for ice sheet height, sea ice freeboard, canopy height, atmosphere, ocean and inland water surface heights; and
4) Be used to develop the ICESat-2 data Algorithm Theoretical Basis Documents (ATBDs), which describe how elevations were retrieved.

MABEL has been flown on high altitude aircraft, for the most part using NASA's ER-2 aircraft out of the Armstrong Flight Research Center. The MABEL beam configuration consists of different angles from nadir and different energies to evaluate ATLAS beams. The beams can be aggregated to develop an ATLAS-like footprint. A summary of all the MABEL Flights to date (April 2015) is shown in the next diagram.



The 2010 and 2011 flights were engineering flights. The first major flight from Armstrong to Greenland was flown in 2012 and collected data sets over land ice and sea ice, as well as over in-transit vegetation and inland water targets. The dark green lines in the above diagram, show the late 2012 East Coast flights, which included a lot of vegetation sites. The Alaska MABEL campaign was carried out in July 2014, and included in transit flights over a number of lakes, summer snow, glaciers, and sea ice.

The noise in MABEL data varies with surface reflectance—higher atmospheric noise is generated by bright surfaces and less noise by dark surfaces. This creates a challenge for retrievals of sea ice, for example. Mike emphasized that a lot more information than just the altimetry can be extracted from the LIDAR data: for example intensity or brightness of surface extracted from the photons in a unit of land or a determination of the type of terrain one is going over.

In order to improve accuracy of algorithms, for example for the inland water product, the penetration effect of MABEL has to be accounted for. One of the mission data products from ATLAS is a 100 signal photon segment elevation over water. An initial attempt to assemble it from MABEL data has been conducted and has shown that water is a lower reflectance target—it produces one photon every 2 meters. It is expected that ATLAS will perform a little better than this, but around the same order of magnitude. The mission will communicate more details as this effort continues to develop.

3.3.2 MATLAS vs. MABEL Data

An ATLAS-like data product generated using MABEL data, MATLAS (http://icesat.gsfc.nasa.gov/icesat2/data/matlas/matlas_docs.php), was created by David Harding, ICESat-2 Project Science Team member. MATLAS aggregates various tracks of the MABEL instrument and also adds noise or changes the reflectance of the surface to generate the 14 m footprint expected for ATLAS. A comparison between ATLAS and MABEL is provided in the diagram below:

MABEL vs ATLAS Instrument

parameter	ATLAS	MABEL
Operational altitude	600 km	20 km
Wavelength	532 nm	532 and 1064 nm
Telescope diameter	1 m	6 inches
Laser PRF	10 kHz	5 kHz
Laser pulse energy	25μJ (weak) & 100μJ (strong) beam	3-5 μJ per beam
Laser footprint diameter	17 μrad (14 m)	100 μrad (2 m)
Swath width	+/- 3 km	+/- 1.05 km

Three things happen when converting airborne MABEL into ATLAS simulation:

- Change sun angle to make the data noisier
- The number of signal photons decreases: ATLAS will have fewer signal photons than MABEL
- Degradation of footprint or spatial blurring: MABEL samples with a 2 m footprint and ATLAS will have a 14 m footprint.

Mike emphasized that people should not feel constrained to use only MABEL data. Other currently available LIDAR Instruments that can be used for pre-ICESat-2 analysis are shown in Appendix D. One example is SIMPL: a dual wavelength sensor (532 and 1064 nm) that flies at a much lower elevation than MABEL. Unlike MABEL, its four beams are exactly collocated. This is considered very important for understanding how the 532 nm wavelength will act for ATLAS, since penetration for the different energies varies for the different land types and because the spatial variability of targets is large. The Science Definition Team is interested in using the SIMPL instrument to understand better the interaction processes of light with the target. SIMPL has been flown since 2009 up and down the east coast covering mostly vegetation sites and also inland water sites and snow sites over Lake Eerie.

All pre-launch data are provided via the ICESat-2 website (http://icesat.gsfc.nasa.gov/icesat2/data.php). Currently, four datasets are available: MABEL, MATLAS, SIMPL, and Sigma Space MPL. For MABEL, camera images, documentation, and readers to navigate through the data are all provided. A general description of the site and data collected can also be found for MABEL. KML files for each MABEL flight and each segment of the flights are also available for visualization.

3.4 National Snow and Ice Data Center (NSIDC) DAAC

The NSIDC will act as the archive and holder of the data coming from ICESat-2. The expected daily data size for ICESat-2 is approximately 900 GB/day. Steve Tanner, ICESat-2 Data Management Lead at the NSIDC, presented an overview of the planned data management tools and services being planned and prepared for the Mission. Located in Colorado, NSIDC is the DAAC for the ICESat-2

Mission. Also present at the workshop from NSIDC were Brian Johnson, newly appointed DAAC manager, and Doug Fowler, also an ICESat-2 Data Management Lead.

NSIDC is currently exploring a new suite of tools and capabilities to reduce data volume and perform on-demand analysis, including using better subsetters and visualizations on site. NSIDC is currently working on two mechanisms for users to search and find ICESat-2 data. It is 1) improving its Reverb and ECHO (http://reverb.echo.nasa.gov/) discovery and access tool, currently available for other datasets, and 2) exploring new ways of bringing information into the GIBS browser (https://earthdata.nasa.gov/labs/worlview/), which provides a way to browse through full-resolution imagery before downloading,

NSIDC is actively assessing the user community for ICESat-2 and collaborating with the ICESat-2 Applications Team to apply feedback into their data services.

4 Feedback from the ICESat-2 User Community

4.1 Early Adopters

Early Adopters are defined as those groups and individuals who have a direct or clearly defined need for ICESat-2 data products, have an existing application or decision making activity, and who are planning to apply their own resources (funding, personnel, facilities, etc.) to demonstrate the utility of ICESat-2 data for their particular application. Application is defined as an innovative use of mission data products in decision-making activities for societal benefit.

The goal of the EA designation is to accelerate the use of ICESat-2 data products after launch of the satellite by providing specific support to Early Adopters who commit to engage in pre-launch research that will lead to the use of the data after launch. It is expected that this pre-launch research will result in a fundamental understanding of how ICESat-2 data products can be scaled and integrated into organizations' policy, business and management activities to improve decision-making efforts. The EA may be either an organization who will use the data in decision making (an 'end user') or a scientist or technical person in a science organization who will conduct the pre-launch research for an end user, and then work with the decision making organization to ensure use of the new product.

For the workshop presentations, the Early Adopters were asked to address the following three questions:

- What decision(s) is your EA research informing?
- What is the expected impact?
- Why should we, as a society, care?

Angela Ottoson, presenting on behalf of Pamela G. Posey from the Naval Research Laboratory, presented research entitled, "Use of ICESat-2 data as a validation source for the U.S. Navy's ice forecasting system." Angela also provided the end user perspective on behalf of the U.S. National Ice Center. Guy Schumann is a designated early adopter as well as end user (main contact and member of the Global Flood Partnership). Charon Birkett is the Early Adopter on inland water and reservoir heights and also presented the end user (USDA/Foreign Agricultural Service) perspective. The table below synthesizes their presentations.

Table 1. Early Adopter Presentation Synthesis

Early Adopter & Organization	End User	Research topic	Methodology	Impact and societal relevance
PI: Pamela G. Posey **U.S. Naval Research Laboratory**	U.S. National Ice Center (NIC)	"Use of ICESat-2 data as a validation source for the U.S. Navy's ice forecasting systems"	IceBridge and MABEL (July 2014) flight data will assist with model validation of the Navy's Arctic Cap Nowcast/Forecast System (ACNFS) and Global Ocean Forecast System (GOFS 3.1) system. The currently operational Arctic Cap Nowcast/Forecast System (ACNFS) delivers daily products of nowcast and 7-day forecasts of ice concentration, ice thickness, ocean currents, and other key parameters to NIC and NOAA.	The NIC expects that improving the quality of data assimilated by ACNFS will enhance the system's prediction capabilities, and will thereby, improve the quality of NIC's ice analyses and tactical sea ice forecast products. Furthermore, NIC expects that this could also result in an increase in the public's understanding of recent changing conditions in the Arctic and Antarctic regions.
PI: Guy Schumann **Joint Institute for Regional Earth System Science & Engineering, University of California, Los Angeles**	Global Flood Partnership (GFP)	"Assessing the value of the ALT13 inland water level product for the *Global Flood Partnership*"	As part of the Early Adopter research, two case studies will explore the potential utility of ATL13 in Niger Inland Delta and San Francisco Bay. Extensively covered by multiple satellite and airborne missions (e.g. SAR, MODIS, SWOT, PRISM), these two regions serve as strong candidates for MABEL and eventual ICESat-2 cal/val targets. Long latency is GFP's main concern; however, ICESat-2 products with latency as long as 30 days could yield better forecasts if used for calibration in global models.	The GFP seeks to integrate the ICESat-2 Inland Water Elevation data product (*ATL137*) into the Global Flood Partnership (GFP) for large-scale hydrodynamic modeling and flood event monitoring activities. The *ATL13* could help with model calibration and validation studies at regional to global scales and has the potential to be assimilated into the GFP operational platform where it may help improve flood mapping and forecasts used to inform decisions made by international aid and development organizations (e.g., decisions made by United Nations rescue missions after flood events).
PI: Charon Birkett **Earth System Science Interdisciplinary Center, University of Maryland**	U.S. Department of Agriculture Foreign Agricultural Services (USDA FAS)	"The Global Reservoir and Lake Monitor (G-REALM): Operations, Research, and Validation with respect to ICESat-2 data products"	The utility of ICESat-2 data products within G-REALM for USDA FAS will depend on ICESat-2's temporal resolution and delay time. A low (seasonal) temporal resolution compared to the monthly resolution required, means that ICESat-2 can only be used as an archival validation source. Charon is currently seeking new G-REALM stakeholders that have requirements for very high-latitude lakes and reservoirs to extend the ICESat-2 EA research to other end users. A potential calibration site is Lake Issyk Kul in Kyrgyzstan, which is well documented with numerous radar instruments such as Jason-2.	G-REALM's primary stakeholder is the U.S. Department of Agriculture's Foreign Agriculture Service (USDA FAS). Through G-REALM, ESSIC provides the USDA FAS with archival and operational information on global lake level variation (proxy for volume of stored water) to inform irrigation potential considerations via its Crop Explorer operational system. The archive measurements help the USDA assess the hydrological drought for a particular lake basin, while the weekly operational information helps the USDA assess the agricultural drought situation within a lake basin.

4.2 Guest Speakers

Guest speakers to the workshop discussed their current use of Lidar data and current requirements and needs for new measurements. Their presentations encouraged dialogue on the potential utility and opportunities for using ICESat-2 data to inform earthquake and coastal zone hazards, and decisions in emergency planning.

Jeanne M. Sauber-Rosenberg, NASA Goddard Space Flight Center
"Illuminating Earthquake Hazards: A Southern Alaska Case Study"
In studying earthquakes and other solid Earth processes, the ICESat-2 LiDAR instrument presents a valuable tool to detect fault and fold structures in remote areas. With a very limited number of methods that can systematically detect ground returns, LiDAR's ability to see beneath the trees is highly desirable for solid Earth applications. For example, the precedent Lidar satellite ICESat was useful for calibration and validation as well as processing of InSAR data, which enabled the development of a comprehensive fault map for Southern Alaska. One particular opportunity for data fusion with L-, C-, and X-band SAR stands out. The potential combination of InSAR and LiDAR data on near fault uplift or subsidence to detect estimated coseismic displacements of greater than 1m would be useful, but only if provided in a timely manner.

John Brock, U.S. Geological Survey Core Science Systems
"3D Elevation Program (3DEP) and Applications in the Coastal Zone"
In response to the critical need for a national LiDAR dataset, the USGS 3D Elevation Program will fill in any gaps in high-quality topography data nationwide over the next 8 years. It will cost-share projects that will fly airborne LiDAR over the conterminous U.S., Hawaii, and the U.S. territories and interferometric synthetic aperture radar (IfSAR) over Alaska. Coastal areas will reap many benefits, especially poorly mapped Pacific Atolls that are vulnerable to inundation hazards exacerbated by sea-level rise. Collaboration opportunities lie in the usage of 3DEP discrete-return airborne LiDAR "bare earth" datasets (2 pts/m^2; 10 cm vertical accuracy) with ICESat-2 elevation data for hazard assessments and calibration/validation efforts. For example, given advance notice of 3DEP's data acquisition schedule and locations, ICESat-2, once launched, could point at the 3DEP sites for calibration. One could also use the 3DEP data as the baseline and use ICESat-2 revisits for change detection analysis. The Earth Resources Observations and Science (EROS) Data Center in Sioux Falls, South Dakota, offers an ideal revisit site for ICESat-2 as it already is a target site for multiple LiDAR acquisitions.

Rafael Ameller, StormCenter Communications, Inc.
"Improving Geospatial Intelligence through Collaboration"
StormCenter Communications, Inc. is willing to explore ways to deliver ICESat-2 data through already existing tools employed by end users to inform decisions in emergency planning. It has engaged the states of Maryland and Alaska, which may benefit from having access to ICESat-2 data in a collaborative web-mapping tool with cross-platform compatibility. While it is not yet clear how and which ICESat-2 data products can be integrated within the crisis management operational framework, StormCenter technologies could be useful for collaboration with end users on algorithm and model development and eventually broader applications. One proposed ICESat-2 application utilizing StormCenter technologies was improving coordination among NOAA, USGS, and U.S. Army Corps of Engineers when hurricanes make landfalls – events that require high-quality elevation data for logistical planning and implementation.

4.3 Breakout Session Feedback

Three breakout sessions were organized to allow participants to learn more about ICESat-2's capabilities for their specific application. The breakout sessions corresponded to applications for different surface cover types (Vegetation & Glaciology, Hydrology, and Sea Ice & Open Ocean) and were led by Tom Neumann, Mike Jasinski, and Sinead Farrell (ICESat-2 Science Definition Team Member for Sea Ice and ICESat-2 Science Team liaison to the U.S. Naval Research Laboratory), respectively.

The breakout session leads were asked to use the following questions developed by the Applications Team to guide the discussions:

1) What is the application question and concept?
    - Known and potential use cases for each theme that are within the scope of the ICESat-2 Mission capabilities.
2) What are the measurement requirements?
    - Current or planned measurements needed to support the application idea. For example, accuracy, spatial resolution, target areas, parameters of interest
3) Who is the potential host agency?
    - Agency to sustain use of application system
4) What is the projected Mission performance?
    - For example, in terms of spatial resolution or average latency
5) What are ancillary measurements?
    - Measurements beyond what is offered by the ICESat-2 Mission products. May also include needed distribution, visualization or integration tools and processing needs

A detailed outline of the break out session discussions can be found in Appendix B. The results will be used by the ICESat-2 Applications Team to expand the Applications Traceability Matrix for ICESat-2 (Appendix C). The following is a list of the organizer's main takeaways from the breakout sessions:

a) Latency required for flooding applications ranges from the best possible latency to 1 day depending on the size of the basin and where it is needed (e.g. Amazon River Basin)
b) A high priority for regional water supply security is being able to detect size of small reservoirs (approximately 10kmx10km in size)
c) Drought is more of an issue than flood for the USDA due to the costs associated with it. Operational lake applications require data with near real time latency or 1 to 2 weeks after satellite overpass.
d) Monthly measurements of snow water equivalency are needed at the state level.
e) With respect to river discharge, ICESat-2 data may improve the accuracy in low flows needed to inform diarrheal disease dynamics, as well as to validate river slopes.
f) ICESat-2, together with ancillary measurements from MODIS and SMAP, can contribute to wall-to-wall global coverage of agricultural vegetation mapping of interest to USDA and the National Geospatial-Intelligence Agency.
g) Linking ICESat-2 data with topographic data from NASA's Shuttle Radar Topography Mission (SRTM) could be used to provide simple ground returns within 1 meter that can inform about high-frequency landslide events in Alaska and be used for monitoring volcano hazards.
h) ICESat-2 offers a valuable mission cal/val opportunity for permafrost monitoring sites on the North Slope.

i) For Oceans, there was a strong need for a greater awareness of Mission product data by the Oceans community. Of particular interest are MABEL flight locations, as well as location and duration of orbit maneuvers.

Overall, the breakout sessions provided guidance on data access, availability and specifically scaled applications that would benefit end users' thematic requirements. There was a strong push from the user community to gain understanding of what they could do better in terms of serving products to the operational community. The National Ice Center (NIC), for example, wants to know how often they should show data and if their services are informative enough to support the broader community (search and rescue, arctic navigation, etc.). Both, the Naval Research Lab (NRL) and the NIC develop decision support tools from the mission products. Knowing what is readily available for testing and operations is of high value.

Appendix A: Questions and Answers for the Mission and NASA HQ

Q&A: Mission Operations

Q: How is the Mission going to classify the photons near coastal boundaries and where things are in flux? Will it do that by actual return or by some class of land mask?
A: Science leads provide definition of surface type – mask is provided and is buffered by about 10 km, but it varies. Buffers causes overlaps- granules can be classified as land ice, sea ice, and ocean and there will be a need to discriminate between each of these.

Q: Will the Mission be operating in repeat track mode or off-pointing mode over Alaska (with particular interest for glaciers)?
A: During the first two years, ICESat-2 will be off-pointing over most of south-east Alaska. Science Team members have asked that some areas be covered in repeat track mode to determine change. After first two years there will be an opportunity to decide what to do over these areas. The six beam configuration and off-pointing plan provides a good number of crossovers—36 individual measurements of change between two reference ground-tracks.

Q: What is the off-pointing angle? And, does the simulated data have a similar off-pointing angle?
A: Maximum operational is 5 degrees, maximum needed to create grid at the equator is under 1.5 degrees. MABEL has a lot of beams and so there will be range of angles across track, but most of it for the near-nadir beams is within 5 degrees. The angle will depend on the aircraft motion. While the aircraft is always rolling, the satellite is much more stable.

Q: What is the highest latitude where off-pointing will occur?
A: Two rules: always in repeat mode over ice-sheets and always in repeat mode over sea ice. Transitions are positioned in such a way that these rules are met. Off-pointing will occur in Alaska and Canada at first and later move to repeat track mode.

Q: How long is off-pointing transition?
A: The spacecraft is capable of flying a lot faster, but the on-board software that tracks surface cannot go quickly. The maximum acceleration is 180 micro- radians per second-square. To get from nadir to off to a-degree-and-half is about 20 seconds with about 5 seconds of settle time. It will be one of the considerations when evaluating target of opportunities.

Q: There is an overlap of LIDAR with imagery in analysis: was there ever a time where the Mission thought about mounting something like a telescopic imager to take coincident imagery with the LIDAR? This would be extremely useful for atmospheric affects, inland water, and knowing what water conditions are.
A: This was not possible for ICESat-2.

Q: Considering a general figure of 50% cloud cover – what are energy levels in terms of penetration?
A: Two atmospheric data products will ultimately generate not just the binary cloud flag (e.g. was it cloudy yes or no), but have an estimate of the optical depth in that area. It is not going to be an absolute measure.

Q: How often are station keeping maneuvers?

A: About every two weeks. Station Keeping Maneuvers will change throughout the Mission depending on beta angle and other things. The coverage is up to 88 degrees north and 88 degrees south. The Mission is geared toward change in the polar areas - coverage in Greenland, Antarctica, Arctic Ocean; hence, the chosen inclination.

Q: With regards to sea height measurement with reflective photons: how well can those photons be discriminated from those that come from deeper down?
A: Several members are looking into water elevation: inland water group, ocean elevation group, and sea ice group. These groups always model the surface physical distribution, but the distribution has not been finalized. Most of the reflectance comes from the surface. Little returns from water have been observed from MABEL: 98% of energy that goes into water decays rapidly due to scattering and absorption. While an important issue, most of what the groups are getting from MABEL is coming from the surface. To get a significant sea height, ocean elevation needs to be retrieved using several thousand signal photons at a scale of several kilometers. There are also issues with slope and bias in the observations, mostly over open-ocean. It is not clear how very small capillary waves are being detected with MABEL.

Q&A: Data Utilization

Q: With regards to disaster response—coastal floods, inland flooding tsunamis of interest to the USGS, what are thoughts on a more rapidly created product in the context of a disaster?
A: There are a couple of limitations: the most rapid product that would be useful in the context of a disaster would be the preliminary level 2A products that have a latency of 4 days, which might go faster—down to 3 days. However, besides latency, another limitation is that disasters cannot be forecasted ahead of time and a request submitted to the queue 30 days before acquisition of the data. The satellite command uploads consist of a 5 day plan and are uploaded every 2-3 days. The orbit would also need to be favorable.

Q: The USGS is involved a lot with bathymetric LIDAR or airborne topobathrymetric LIDAR: given that MABEL and ATLAS have a 532 channel, is there a possibility to get any bathymetry out of ICESat2 in shallow clear water over carbonate platforms?
A: Yes. For example, Chris Parrish who is involved with programs such as the airborne SHOALS program for measuring coastal bathymetry, has found bottom topography in one of the MABEL flights over the Chesapeake Bay. One of the problems is that the MABEL flights have been done over relatively turbid water, which means that a process is required for identifying areas that are clear to penetrate deeper. ICESat-2 does not have the energy in the laser to get bathymetry over short distances. It is not expected that bathymetry will be a routine parameter.

Q: How much advance notice is needed for off-pointing to support a particular research project?
A: Nominal timeline: at least 30-days in advance to go through de-conflict processes and evaluation. Five days is the least number of days based on command-upload timeline, but further in advance is better. The process is not going to be a black box—requests will be acknowledged and status and instructions will be communicated all the way through to the end.

Q: Are requests for episodic acquisitions possible with ICESat-2?
A: It will be possible to submit one time or recurring requests.

Q: Other than NASA airborne surveys, are there any other entities out there planning to work with ICESat-2 airborne campaigns?

A [DAAC]: NSF is flying other airborne missions intended to underfly ICESat-2.

Q [Suggestion]: An inter-comparison between Jason-2 and MABEL would be really useful for analysis of ocean returns. For example: fly MABEL along a Jason-2 ground track within half-an-hour of a Jason-2 overflight.
A [Mission]: Right now most of the cal/val sites that the Mission is identifying are being identified by the SDT members. They are responsible for knowing what the community has. If you have knowledge of a long term monitoring site—a large target, not just a single gage—let the Project Office know by email. The Project Science Office is not exhaustive in its knowledge. Kelly Brunt is putting together cal/val documents for long term cal/val sites. The validation program for ICESat-2 includes monitoring, but also very specific experimental sites.

Q [Suggestion]: Jason-2 project and its antecedents have developed in-situ calibration sites which have long histories. Its Harvest site, for example, has a twenty year time history and other sites have time histories of at least 10-15 years. It would be very useful to instrument those sites so they could obtain data from ICESat-2. This would allow one to better interrelate data from Jason with data received from ICESat-2.
A [Applications]: The Applications Team can survey the community for cal/val sites and send information to Project Science Office so that they are aware of any future sites suggested from the ICESat-2 community at large.

Q&A: Data Availability & Access

Q: Will there be ground truth for validation
A: Yes, it is currently being planned by the Mission Team.

Q: What are the ground stations?
A: Svalbard and Poker Flat, Alaska

Q: Will data on oceans be captured?
A: Yes, all data will be captured and there will be a global ocean product.

Q: Will KMZ files will be made available prior to launch?
A: Yes, these are important for calibration and validation.

Q: Regarding metadata, are they available in a structured machine readable format? Specifically, in XML?
A: All the data products are provided in HDF5 format. The metadata is one group in the HDF5 structure. Metadata for ICESat-2 is XML readable and on MABEL it is not; however, it can be readable if something like HDF View is used.

Q: If user wants ICESat-2 LIDAR over a certain region, can NSIDC automatically provide the most recent imagery for that data so as to be able to get collocated in space and time imagery that is close enough for some analysis?
A [DAAC]: This is the kind of thing that NSIDC wants to do, since it would limit the stuff that users would need to do.
A [Mission]: We hope the DAAC will provide those kinds of capabilities. The Mission has been looking into a coincident or near-coincident ICESat-2 and Landsat 8 or Landsat 9 comparable data.

Q: What is the NSIDC DAAC's schedule for tools and what do you have available now?

A: Tools discussed in presentation are available now, in general, across data products. The DAAC assumes they will be able to use these tools with ICESat-2 data. New capabilities need to be defined and scheduled. Results of BEDI work will be ready in 2015, i.e. spatial and parameter subsetting capabilities that will apply to ICESat-2 will be available before launch. Further and actual analysis will need to be brought online as possible moving forward.

Q: Will there be an opportunity to link to the Early Adopter research through the DAAC and then also have the Early Adopters link back to the DAAC (this in an effort to create fluid communication between the scientific research and the operational potential of the products)? If of interest, the Applications Team will start work to support that.
A: Yes, DAAC would want to support that. NSIDC is still trying to understand what the scope of work is for ICESat-2. A proposal was submitted to understand scope. NSIDC considers this a good point to have this discussion. The ICESat-2 team has involved the DAAC much earlier than what NSIDC is typically used to. NSIDC expects that this will allow it to understand and respond to requests much better than just after the fact. NSIDC also pointed out that ESDIS has been very supportive in trying to respond to these kind of requests.

Q: With respect to ICESat-2 calibration/validation airborne campaigns, will these data be available from the same source?
A [Mission]: Currently aircraft data are provided through Goddard pages. Mission has not worked out yet with NSIDC how it will handle post launch cal/val data, like aircraft data.
A [DAAC]: Cal/val is an open item in terms of whether and how it can be hosted. For example, DAAC identifies "Golden Days" where IceBridge is flying under various satellites and provides data as separate IceBridge products.

Appendix B: Breakout Sessions Synthesis

Hydrology Breakout – Lead: Mike Jasinski

What is the applications question and concept?	1) Navigation, reservoir operation, transportation: Mississippi Ohio rivers, ice conditions, lake ice 2) General use, agriculture, fisheries, regional security (California drought system/water security) 3) Energy, e.g. hydropower 4) Ecosystem wetlands and conservation, ecology 5) Flooding (coastal flooding, hurricane type flooding), irrigation and recreation/tourism, storm surge 6) Mining, mini ponds 7) Operational lake monitoring 8) Mountain snow 9) Fire	
What are the measurement requirements?	**<u>Flooding</u>** • Geospatial/Temporal requirements (direct use): anything better than ½ meter; Looking for absolute. • Over what temporal space? Some floods stay for months, so can be back in channel very quickly (1 day). Depends on the scale of the basin. • Latency of the product for storm surge – 2 days; short-intervals. For the Amazon, for example, it does not matter when you get the data. The best possible latency is needed for floods. No exact repeats possible. **<u>Water Supply</u>** • Regional Security- latency: daily updates; There are many new reservoirs being built. Breaking through the size barrier is a high requirement for security (get to smallest reservoirs possible, i.e. ~10km). • Drought: part of USDA requirement listed above **<u>Rivers</u>** • Every kilometer (complications: turbid rivers and downstream distance). **<u>Navigation</u>** • 3 days, near real time, seasonal (?), Ice Damming (seasonal)	**<u>Snow</u>** • Right now measurements with Snow Telemetry (SNOTEL). They would be happy to get snow water equivalent—not needed daily, but monthly. For the state that would be very useful. Monthly would be useful – NSIDC send out people to these measurements. Custom densities for places not accessible to give you a better time series. • Can ICESat-2 do ½ inch monitoring (avalanche prevention)? Slope and depth are needed for avalanche prevention (niche market-limited scope).[2] • Glacial melt: kilometers, big enough to feed system (km x km wide). Build up time series with monthly transects. What average change in volume (combine with imagery to figure out how much ice is lost). Average change – 10 centimeters (same requirements a glacial monitoring). **Contact C.K. Shum for targets.** **<u>Coastal mapping</u>** • Sub-surface bathymetry, but also coastal plains • Depends also on fast changing features/smaller objectives – scales are on the yearly • Shallow coastal modelling – very difficult and uncertain. Shallow coastal tidal modeling

[2] In general, 1/2 inch of range precision is not possible in areas of likely avalanches. The range precision in such areas is driven by the surface slope, which tends to be large in areas with potential avalanche hazard.

Hydrology Breakout – Lead: Mike Jasinski (cont.)

What are the measurement requirements?	**<u>Public Health</u>** • With respect to diarrheal diseases. Low flows are not accurate; elevation models to link to ICESat-2 – better idea of local conditions; **<u>Operational Lake</u>** **USDA:** • Global coverage -40S and +52 N; 10 cm accuracy (not on an individual height segment, but over time series; deviation from truth); ideally near-real time, history of recent measurements (going back a couple of decades); temporal frequency – once per month at a minimum and delay on the data (near-real-time wise – 1 to 2 weeks after satellite overpass). 3 – 4 times are year is not acceptable. Same repeat path over lake – exact repeatability is good (not different times) • Survey of end-users: ¾ interested in information now (a couple of weeks after overpass) • Drought is more of an issue than flood for the USDA – it costs more. It is the most expensive application for the USDA.	**<u>Discharge</u>** • Independent validation of SWOT – instantaneous discharge every 10-20 days. ICESat-2 can deliver height and slope- validation of river slopes. • Archive of everything of interest – ICESat-2: has not been decided yet – compute the river shapefile from SWOT (# river crossings). Analysis will require sharing of water body shape files-there are a lot of things that we could share in between the Missions.

Vegetation & Glaciology Breakout – Lead: Tom Neumann

<table>
<tr><td>What is the applications question and concept?</td><td colspan="2">1) Deforestation Trends
2) Wildfire Monitoring
3) Landslide Warnings
4) Volcanic Monitoring and Geohazard Identification
5) Aerosol Monitoring
6) Agricultural Vegetation Mapping
7) Shrubland Characterization
8) Permafrost Observations
9) Forest Structure Visualization
10) Urban Tree Canopy Mapping
11) Earthquake Warning System
12) Wetland Mapping</td></tr>
<tr><td>What are the measurement requirements?</td><td><u>Landslide Warnings</u>
• Focus on high-frequency events in Alaska, simple ground return within 1m
Ancillary Measurement: SRTM
<u>Volcanic Monitoring & Geohazard Identifications</u>
• simple ground return within 1m, global gridded earth surface and canopy height
Ancillary Measurement: SRTM
<u>Agricultural Vegetation Mapping</u>
• Wall-to-wall coverage preferred, good uncertainty, global coverage
Ancillary Measurement: MODIS, SMAP</td><td><u>Urban Tree Canopy Mapping</u>
• Sub-1m

<u>Earthquake Warning System</u>
• Simple ground return within 1m</td></tr>
</table>

Vegetation & Glaciology Breakout – Lead: Tom Neumann (cont.)

Who is the potential host agency?	**<u>Deforestation Trends</u>** • USFS • USAID • State Department **<u>Landslide Warning</u>** • Park Services **<u>Volcanic Monitoring & Geohazard Identification</u>** • USGS (Volcano Hazards Program) • LCCs • Native American Corporations **<u>Aerosol Monitoring</u>** • FAA **<u>Agricultural Vegetation Mapping</u>** • USDA • Department of Defense (NGA) **<u>Shrubland Characterization</u>** • USFSW **<u>Others:</u>** 1) USFS, Resource Planning Act (inventory of carbon stocks), perhaps calibration/validation of FIA network in coordination with G-LiTE? 2) USAID, a potential end user for LiDAR 3) World Resources Institute, Global Forest Watch 4) Google Inc.	**Comments:** • More emphasis on real-time data. • Calibration and Validation opportunities with ABoVE, may be duped by cloudy days. Valuable opportunities on permafrost monitoring sites on the North Slope. • Employ data fusion with InSAR data, as ground control points • Looking to leverage NISAR if there is overlap. ALOS/PALSAR are continually used because they are consistent over the years. • Model validation studies for climate studies (ex. Validation with flux towers) • ICESat-2 may be more useful for inventory purposes, rather than change detection. • Backdrop picture for high-resolution (advantages: temporal continuity, global coverage) • NGA has offered Jeanne a letter of support for mission facilitation.

Sea Ice & Open Ocean – Lead: Sinead Farrell

Critical needs	Data Tools	Follow Up
1) Sea ice type categories and masks. The National Ice Center (NIC) creates these weekly, but we could use these more regularly. 2) Location and duration of orbit maneuvers and cal/val operations—ocean scans. A webpage to update users regularly. 3) Synthesis of datasets—e.g. SMAP and ICESat-2. For example, at NSIDC they could provide the latest SMAP (or other satellite) dataset at the location of the ICESat-2 segment 4) Along-track resolution of ocean data? Minimum resolution of aggregated returns over open-ocean. 5) MABEL freeboard product—conversion of MABEL elevation data to freeboard. 6) Capturing uncertainty in ice masks or model forecasts is useful for Polar Code. Discussed cone of uncertainty: represent ice type as percent likelihood.	1) Web mapping services and providing data in tiled format. Utility of interactive maps and data availability on mobile platforms. 2) Cal/Val ops: Jason-2 and other RA altimeters for cal/val over oceans.	What is the timeframe for the availability of the ATBD documents to: Early Adopters? Public? Note: some Early Adopters may be interested in providing feedback on ATBDs, but if that is not needed, then just being able to read them would be helpful.[3]

[3] ATBDs are currently being written and the Project Science Office is currently not planning on making them publicly available prior to launch. The only one that is publicly available is Ron Kwok's Sea Ice algorithm, key elements of which have been published here:

Kwok, R., T. Markus, J. Morison, S. P. Palm, T. A. Neumann, K. M. Brunt, W. B. Cook, D. W. Hancock, and G. F. Cunningham. (2014), Profiling sea ice with a Multiple Altimeter Beam Experimental Lidar (MABEL), J. Atmos. Oceanic. Technol., 31(5), doi: 10.1175/JTECH-D-13-00120.1.

Appendix C: Applications Traceability Matrix (example entry)

Application Question	Application Concept	Application Measurement Requirements	Applied Sciences Category	Potential Host Agency	Early Adopter	Mission Data Product	Projected Mission Performance	ARL	Ancillary Measurements Identify any required external products
Are ships able to navigate through the Arctic in current conditions?	Since the 1950s there has been a rising frequency and intensity of arctic storms. There is a need for better forecasts of weather, ocean and sea ice conditions. Reductions in sea ice extent, duration and thickness have the potential to increase the frequency and amplitude of storm surge and increase the highly seasonal vessel activity in the Arctic.	The U.S. Naval Research Laboratory (NRL) has an operational responsibility to provide daily updates of sea ice conditions to vessels navigating through the Arctic. The Arctic Cap Nowcast Forecast System (ACNFS) provides nowcasts and forecasts of sea ice conditions in the Northern Hemisphere. The NRL is interested in ice thickness and sea ice freeboard data for assimilation into the ACNFS or for model validation to improve ice edge forecasts for the entire Arctic Marginal Ice Zone (MIZ)	Oceans	National Ice Center	PI: Pam Posey	Global Geolocated Photon Data ATL03; Sea Ice Height ATL07; Sea Ice Freeboard ATL10, Gridded Sea Surface Height - Open Ocean ATL19 Gridded Sea Ice freeboard ATL20; Gridded Sea Surface Height – Ice Covered Ocean ATL21	ICESat-2 will acquire year-round data over ice-covered oceans, different seasons and through seasonal transitions. It will 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. .	4	Operation IceBridge LiDAR, radar and imagery data; NRL airborne surveys over the Arctic sea ice off the coast of Barrow, Alaska and other field work measurements.

Appendix D: Other LIDAR Instruments for pre-ICESat-2 Analysis

Other LIDAR Instruments for pre-ICESat2 Analysis (Non Exhaustive)

Parameter	ATLAS	MABEL	SIMPL	G-LiHT	Sigma HRQLS	UT AHAB	LVIS	ATM	ALIRT
Operational altitude	496 km	20 km	2.5 km	0.3 km	2-5 km	0.4 km (bathy) - 1.5 km (topo)	10 km	0.4-0.8 km	3-10 km
Wavelength	532 nm	532 nm and 1064 nm	532 nm and 1064 nm	1550 nm	532 nm	515 nm and 1064 nm	1064 nm	532 nm	1064 nm
Laser pulse repetition rate	10 kHz	variable 5-25 kHz	11.6 kHz	50-300 kHz	25 kHz	Green< 35 kHz NIR<400 kHz	< 500 Hz	2-10 kHz	15 kHz
Number of beams	6 @ 532 nm	16 @ 532 nm, 8@ 1064 nm	2@ 532 nm 2@1064 nm	1	100	1	1	1	1
Collection mode	photon-counting/profiling	photon-counting/profiling	photon-counting/profiling	discrete return/swath mapping	photon-counting/swath mapping	Full-waveform/swath mapping	Full-waveform	Full-waveform	Geiger-mode swath mapping
Laser pulse energy per beam	164 µJ and 41 µJ		532: 0.13 µJ, 1064: 0.3-0.8 µJ		1.05 nJ		5 mJ	250 µJ	3 nJ
Across-track beam spread	constant 13.2 mrad: 6.5 km	2 km	16 km	387 m	±1.3 - 2 km		2 km		±1.3 - 2 km
Laser beam divergence	20 µrad	76 µrad	100 mrad			3 mrad green, 5 mrad nir			
Footprint size@altitude	10 m	2 m	0.2 m		5 m x 5 m	30 cm NIR; 1 m Green	10 -25 m	1 m	
Laser pulse polarization	n/a	n/a	plane	n/a	n/a	n/a	n/a	n/a	n/a
Telescope diameter	0.8 m	0.15 m	20 cm				20 cm		.05 m
Detector configuration	4 for weak beams 16 for strong beams: all PMT channels have individual timing	PMT channels with independent timing for each beam	4; two wavelengths and 2 polarizations (16 channels)		10 x 10 focal plane	Si:APD	Si:APD	PMT	32 x 128 focal plane
Beam pattern	3 pairs of beams (strong/weak): 6.6 mrad (3.3 km) btw strong cross track: 5 mrad (2.5 km) btw strong and weak along track rotated for 90 m cross track btw strong and weak	variable channels and beam configuration	2 coincident beams (same optical path	n/a	100 beamlets collectively creating a footprint	n/a	n/a	n/a	n/a
Detector FOV	83 µrad / 40 m diameter	210 µrad/ 4.2 m	233 µrad / 0.6 m		50 cm pixels		8 mrad	2.1 mrad	30 cm pixels @20 kft
Reciever dead time	~3 nsec	~3 nsec	50 nsec	n/a	1.6 nsec	n/a	n/a	n/a	1 msec
receiver impulse response monitor	Recorded twice per orbit for 2 beams?	planned laboratory measurements	laboratory measurements	not recorded	not recorded	recorded every pulse	recorded every pulse	recorded every pulse	not recorded
Ranging precision	34 cm	34 cm			20 cm				10 cm
Ranging accuracy (flat surface)	36 cm				< 1m	10 cm		2 cm	< 1m
geolocation or horizontal	6.5 m	20 m			~1m	20 cm		15 cm	< 1m
Platform	s/c	ER-2			KA B200	fixed wing	fixed wing	P-3B and DC-8	G3
Point density					~10 pts/m^2	~12 pts/m^2			>30 pts/m^2

Source: Lori Magruder, ARL, Univ Texas, Austin

Appendix E: ICESat-2 Science Data Product Table

The planned ICESat-2 science data products are shown in Table 1. The products will conform to the HDF-5 standard.

ICESat-2 Science Data Products

Product Number	Name	Short Description	Latency*
ATL00	Telemetry Data	Raw ATLAS telemetry in packets with any duplicates removed by EDOS.	Downlinked 8 times per day
ATL01	Reformatted Telemetry	Parsed, partially reformatted, HDF5 time-ordered telemetry.	2 days
ATL02	Science Unit Converted Telemetry	Science unit converted time ordered telemetry calibrated for instrument effects. All photon events per channel per shot. Includes atmosphere raw profiles. Includes housekeeping data, engineering data, s/c position, and pointing data.	2 days
ATL03	Global Geolocated Photon Data	Precise lat, long and height above ellipsoid for all received photons determined using POD and PPD. Along-track data, per shot per beam. Geophysical corrections applied. Classification of each photon (signal vs. background) and into surface types (land ice, sea ice, ocean, etc…).	21 days
ATL04	Normalized Relative Backscatter	Along-track atmosphere backscatter data at full instrument resolution. The product will include 14 km uncalibrated attenuated backscatter profiles at 25 times per second for ~30m vertical bins. Includes calibration coefficient values for the polar region.	21 days
ATL06	Land Ice Height	Surface height for each beam, along and across-track slopes calculated for beam pairs. All parameters are calculated at fixed along-track increments for each beam and repeat.	45 days
ATL07	Sea Ice Height	Height of sea ice and open water leads (at varying length scale). Includes height statistics and apparent reflectance.	45 days
ATL08	Land-Vegetation Height	Height of ground and canopy surface at fixed length scale. Where data permits, include estimates of canopy height, relative canopy cover, canopy height distributions, surface roughness, surface slope and aspect, and apparent reflectance.	45 days
ATL09	Calibrated Backscatter and Layer Characteristics	Along-track cloud and other significant atmosphere layer heights, blowing snow, integrated backscatter, and optical depth.	45 days
ATL10	Sea Ice Freeboard	Estimates of freeboard using sea ice elevations and available sea surface height within km length scale; contains statistics of sea surface samples used in the estimates.	45 days
ATL11	Land Ice H(t)	Time series of height at points on the ice sheet, calculated based on repeat tracks and/or crossovers.	45 days from receipt of last data in product
ATL12	Ocean Surface Height	Surface height at varying length scales. Where data permits, include estimates of height distributions, surface roughness, surface slope, and apparent reflectance.	45 days from receipt of last data in product
ATL13	Inland Water Body Height	Along-track inland water height. Where data permits, includes roughness, slope and aspect.	45 days from receipt of last data in product
ATL14	Antarctic and Greenland Gridded Height	Height maps of each ice sheet for each year of the mission, based on all available ICESat-2 elevation data.	45 days from receipt of last data in product
ATL15	Antarctic and Greenland Height change	Height-change maps of each ice sheet, with error maps, for each mission year and for the whole mission.	45 days from receipt of last data in product
ALT16	ATLAS Atmosphere Weekly	Polar cloud fraction, blowing snow frequency, ground detection frequency.	45 days from receipt of last data in product
ATL17	ATLAS Atmosphere Monthly	Global cloud fraction, blowing snow and ground detection frequency.	45 days from receipt of last data in product
ATL18	Land-Vegetation Gridded Height	Gridded ground surface height, canopy height and canopy cover estimates.	45 days from receipt of last data in product
ATL19	Gridded Sea Surface Height – Open Ocean	Gridded ocean height product including coastal areas. TBD grid size. TBD merge with Sea Ice SSH.	45 days from receipt of last data in product
ATL20	Gridded Sea Ice freeboard	Gridded sea ice freeboard. (TBD length scale)	45 days from receipt of last data in product

* Latency is defined as the approximate time it takes from the data acquisition on a satellite until it reaches an individual in a usable format.

Appendix F: Workshop Agenda

10 March, Tuesday		
8:30am	Registration and Coffee	
9:00am	*Woody Turner, NASA HQ {5 min}*	Workshop Welcome
9:05am	*Vanessa Escobar, ICESat-2 Mission Deputy Program Applications Lead {15 min}*	Welcome, Workshop Objectives, Charge to Workshop
9:20am	*Thorsten Markus, ICESat-2 Mission Project Scientist{20 min}*	ICESat-2 Mission Overview & Science Objectives
9:40am	*Sabrina Delgado Arias, ICESat-2 Deputy Applications Coordinator & POC {15 min}*	Mission Applications & Strategy for Workshops
9:55am	Morning Break	
10:10am	*Tom Neumann, ICESat-2 Mission Deputy Project Scientist{25 min}*	ICESat-2 Data Product Suite Overview
10:35am	*Mike Jasinski, ICESat-2 SDT Member and Applications Liaison to the Mission{25 min}*	Overview of MABEL and MATLAS simulated data
11:00am	*Steve Tanner & Doug Fowler, National Snow and Ice Data Center{15 min}*	ICESat-2 Data Management at NSIDC DAAC
11:15am	**Q&A Panel with Mission & DAAC**	
12:00pm	**LUNCH 12:00-1:30pm** **Poster Session During Lunch**	
1:30pm	*Sabrina Delgado Arias, ICESat-2 Deputy Applications Coordinator & POC{10 min}*	ICESat-2 Early Adopter Program
1:40pm	*Angela Ottoson, U.S. National/Naval Ice Center {20 min}*	Use of ICESat-2 Data as a Validation Source for the U.S. Navy's Ice Forecasting Models ***End-User:*** National/Naval Ice Center; POC: LTJG David Keith, ***SDT Partner*:** Sinead L. Farrell, University of Maryland
2:00pm	*Guy Schumann, Joint Institute for Regional Earth System Science & Engineering, University of California, Los Angeles{20 min}*	Assessing the value of the ATL13 inland water level product for the Global Flood Partnership (GFP) ***End-User:*** *GFP; POCs: Guy Schumann & Dr. Florian Pappenberger, ECMWF* ***SDT Partner:*** Michael Jasinski, NASA GSFC
2:20pm	*Charon Birkett, Earth System Science Interdisciplinary Center – University of Maryland{20 min}*	The Application of Altimetry Data for the Operational Water Level Monitoring of Lakes and Reservoirs ***End-User:*** USDA/FAS, POC: Dr. Curt Reynolds ***SDT Partner:*** Michael Jasinski, NASA GSFC
2:40pm	**Q & A Panel Early Adopters & End Users**	
3:00pm	**Afternoon Break**	
3:15pm	Breakout Session: **what are known and potential ICESat-2 applications?** Project Team and SDT members will be co-chairs for two concurrent breakout sessions. The breakout sessions will be **organized by the following potential themes**: Vegetation, Arctic & Sub-Arctic Hydrology, Open Ocean, Sea Ice, Glaciology, and Atmosphere. Main topic: 1. Planned ICESat-2 data products by theme (i.e. vegetation, hydrology, open ocean, etc.) 2. Existing community data, tools, and modeling resources 3. Data and knowledge limitations/gaps for addressing key policy challenges and uncertainties 4. Three/four use cases for current critical needs	
	[Potential Theme] *applications*	**SDT Lead for Breakout** / **Related Early Adopters (PIs)**

Appendix F: Workshop Agenda

10 March, Tuesday			
	[**Vegetation**] *land management: land-use, agriculture, forestry, tourism, habitat biodiversity, construction*	Lead: Tom Neumann	N. Glenn; L. Abbott; B. Peterson;
	[**Hydrology**] *operational planning and forecasting; Mining, oil and gas pipelines; Navigation, hydro power; Fisheries, tourism; post-fire recovery*	Lead: Mike Jasinski	C. Birkett; G. Schumann; K.H. Tseng;
	[**Open Ocean**] *sea level monitoring; coastal inundation and restoration; ship traffic; fisheries; marine safety; oil spill forecasting; marine faunal surveys; commercial navigation; military defense*	Lead: Thorsten Markus	S. Nagarajan
	[**Sea Ice**] *Maritime navigation; oil and gas; shipping; fishing; search and rescue; telemedicine; tourism*	Lead: Thorsten Markus	P. Posey; A. Roberts; A. Jahn; A. Turner; A. Mahoney; S. Howell;
	[**Glaciology**] *volcanic hazard assessment; water resource management; tourism industry; insurance; agriculture; regional planning*	Lead: Tom Neumann	G. Babonis;
	[**Atmosphere**] *air quality forecasts; public health; aviation safety; ash fall: agriculture (livestock), buildings, waste water systems, water supply*	Lead: Yuekui Yang	L. Mona
4:30pm	Vanessa Escobar, Thorsten Markus	Closing Remarks & Announcements	
5:00pm	**Day 1 Adjourned** **Poster Session until 5:00pm, Social Dinner to follow Poster Session**		
11 March, Wednesday			
8:30am	Registration and Coffee		
9:00am	*Vanessa Escobar, ICESat-2 Mission Deputy Program Applications Lead{15 min}*	Recap of Day 1, Objectives for Day 2, Charge to Breakout group summaries	
9:15am	*5 minute informal (no presentation) summaries from each breakout group lead & discussion by entire group*		
10:15am	**Morning Break**		
10:30am	*Jeanne M. Sauber Rosenberg, NASA {20 min}*	Illuminating Earthquake Hazard	
10:50am	*John Brock, USGS{20 min}*	3D Elevation Program (3DEP) and Applications in the Coastal Zone	
11:10am	*Rafael Ameller, StormCenter Communications, Inc {20 min}*	Improving Geospatial Intelligence Through Collaboration	
11:30am	**Q & A with Guest Speakers**		
12:00pm	**LUNCH 12:00-1:30pm**		
1:30pm	**Panel** ***Open discussion – Identify potential collaborations and opportunities*** 1. *What are potential Cal/Val opportunities-collaboration?* 2. *What studies could we do to determine if the sensor will have the appropriate accuracies and information needed for certain applications?* 3. *How can ICESat-2 best integrate its user community?*		
2:00pm	*Vanessa Escobar {15 min}*	Closing Remarks, Announcements & ICESat-2 Community Questionnaire Discussion	
2:15pm	**ICESat-2 Workshop Adjourned** ***Thank you for your Participation!***		

Appendix G: List of Participants

Workshop Participants

Name	Organization
Alvaro Ivanoff	NASA GSFC
Antar Jutla	West Virginia University
Assaf Anyamba	USRA & NASA GSFC
Brian Gunter	Georgia Institute of Technology
Brian Johnson	National Snow and Ice Data Center
Charlene DiMiceli	University of Maryland
Claudia Carbajal	Sigma Space at NASA GSFC
David Harding	NASA GSFC
David Keith	U.S. National Ice Center
Douglas Fowler	National Snow and Ice Data Center
Elias Deeb	Cold Regions Research and Engineering Lab
Elizabeth Hoerner	U.S. National Ice Center
Elizabeth Hoy	NASA GSFC/GST
Frank Lemonie	NASA GSFC
James Carton	University of Maryland
Jinzheng Peng	NASA GSFC
Jonathan Resop	University of Maryland
Justin Goldstein	US Global Change Research Program
Kate Ramsayer	NASA Goddard/Telophase
Lucia Woo	SSAI NASA/GSFC
Lynn Abbott	Virginia Tech
Mark Middlebusher	NAVOCEANO support
Michael Galvin	USFS Northern Research Station/SavATree
Molly Brown	University of Maryland
Nancy Harris	World resources institute
Oscar Colombo	USRA/GESTAR
Patricia Vornberger	SGT, Inc. at NASA GSFC
Patrick Whelley	NASA GSFC
Sinead Farrell	University of Maryland/NASA/NOAA
Tian Yao	USRA
Valerie Casasanto	UMBC JCET/NASA GSFC
Wenge Ni-Meister	Hunter College of The City University of New York
Yohanes Sulistioadi	NASA Goddard Space Flight Center
Yuekui Yang	USRA

Remote Participants

Name	Organization
Nancy Maynard	U.Miami/CIMAS/RSMAS
Andrew Brenner	Quantum Spatial
Paul Reich	USDA NRCS
Li	NRL
Everett Hinkley	Forest Service

Appendix G: List of Participants

Workshop Speakers

Name	Organization
Angela Ottoson	U.S. National Ice Center
Charon Birkett	University of Maryland
Guy Schumann	UCLA-JIFRESSE
Jeanne Sauber	NASA GSFC
John Brock	USGS
Michael Jasinski	NASA GSFC
Rafael Ameller	StormCenter - GeoCollaborate
Sabrina Delgado Arias	SSAI NASA/GSFC
Steve Tanner	NISDC
Thorsten Markus	NASA GSFC
Tom Neumann	NASA GSFC
Vanessa Escobar	SSAI NASA/GSFC
Woody Turner	NASA Headquarters