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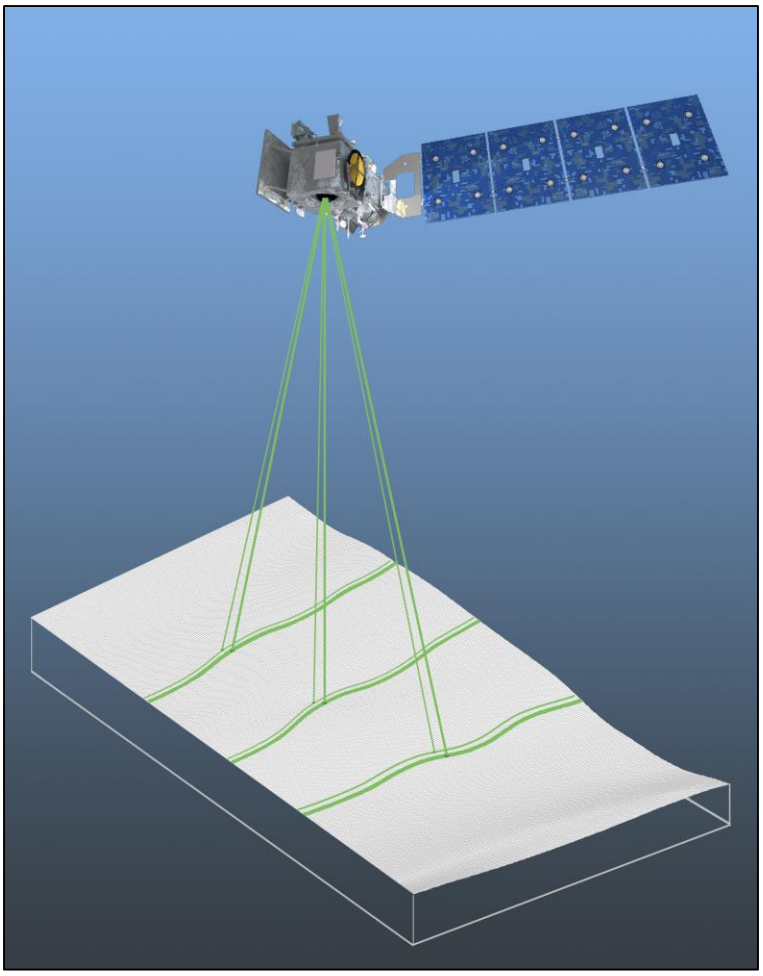

Ice, Cloud, and Land Elevation Satellite 2 (ICESat-2) Applications Plan

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The Applications Team for ICESat-2 consists of Molly Brown (Applications Coordinator), Vanessa Escobar (Deputy Applications Coordinator), Thorsten Markus (Project Scientist), Tom Neumann (Deputy Project Scientist), and Michael Jasinski (SDT Lead for Inland Water; SDT Applications Contact). This team will implement the initiatives and programs outlined in this document.

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1. Introduction

NASA Earth Sciences division is dedicated to developing a more complete understanding of the Earth and all of its systems. Through research driven missions NASA has been able to answer science questions that help unravel the complexities of the Earth's climate and environmental systems primarily through the design and deployment of remote sensing systems. Satellite and airborne remote sensing datasets can be integrated into models and decision support systems that enable improved natural resource management, disaster prevention and response, and other benefits to society[1].

The overarching purpose of the NASA Applied Sciences Program is to discover and demonstrate innovative uses and practical benefits of NASA Earth science data, scientific knowledge, and technology. The Applied Sciences program solicits grant proposals through NASA's Research Opportunities in Space and Earth Sciences (ROSES) program in 9 themed areas from disaster management, to water resources management and health and air quality (http://appliedsciences.nasa.gov/index.html). The goal of the Applied Sciences program is to promote the use of satellite data by public and private organizations to help support decision making activities and services.

In 2007, the National Research Council released the first Decadal Survey for Earth Science. The Decadal Survey outlined research prerogatives and initiatives of national importance for the next decade and identified development of applications of satellite data as a priority for all future missions. The Applied sciences division responded to this by identifying applications leads for all Tier 1 Decadal Survey missions. The intent is for the applications leads to engage with the project science and development teams during the pre-launch development process and to facilitate interaction with the relevant communities of users to ensure that mission data products will achieve maximum value.

By engaging relevant communities in the pre-launch development stage of a satellite mission, it will be possible to generate applications-relevant data products at launch. Connecting end users of data with science data product developers and distributors such as the Distributed Active Archive Center (DAACs) increases the visibility of the products and provides opportunities for feedback on products early in the development phases of the mission. Through this effort, applications and operational users may be able to insert data products into existing systems earlier on in the mission lifespan, enabling the maximum benefit to society from each satellite mission.

The relevant communities of end users can be characterized into two groups, (1) the *community of practice* (those users who traditionally use satellite remote sensing data in processes or decision support) and (2) the *community of potential* (those individuals who do not currently use the satellite data products but either have applications that could benefit and/or have the ability to use the data but do not currently do so). Individuals or organizations in both communities can be public or private, Federal or local entities, and can have a local, national or international scope for their application.

The Ice, Cloud and Land Elevation Satellite – 2 (ICESat-2) mission is a Tier 1 Decadal Survey mission expected to launch in 2016. The Applied sciences program is engaging mission development through the project science team on this mission to help inform the community of practice on details of the mission and its products to develop the community of potential into a robust community of practice.

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[1] This ICESat-2 Applications plan has been adapted from the SMAP Applications plan http://smap.jpl.nasa.gov/files/smap2/SMAP_Apps_Plan1_120423.pdf .

The objective of this ICESat-2 Applications Plan is to provide the strategic vision for the applied sciences effort for the ICESat-2 mission from the early development phases through the launch of the satellite.

For the applications program, the following specific activities and initiatives will be undertaken:

- Host interactive workshops, focus sessions and tutorials to engage the community of practice and potential.
- Establish an Applications Working Group to expand applications outreach.
- Establish an Early Adopter program to demonstrate societally relevant applications to proposed data products.
- Develop cross mission activities to establish connections between the ICESat-2 community and other NASA missions communities through Applications tutorials.
- Work with the National Snow and Ice Data Center to ensure that ICESat-2 products are easily accessible.

The overarching objective of the applications program is to broaden and strengthen the knowledge and engagement of the research and applications communities with the ICESat-2 mission. The intent is to understand the needs of this community, and work with the SDT and the project science team to ensure that these needs are met.

2. ICESat-2 Mission Description

The first Ice, Cloud, and land Elevation Satellite (ICESat) was developed in the 1990's and was designed for measuring the rate of change of the world's ice sheets and sea ice. This system operated from 2003 to 2009 and provided the multi-year elevation data needed to determine change in ice sheets, sea ice, land elevations and tree canopies. The Geoscience Laser Altimeter System (GLAS) instrument aboard ICESat was the first space borne LiDAR instrument for Earth science. This instrument collected data during specified campaigns with consistent repeat coverage over the polar regions and at strategic locations at lower latitudes (the system was operated in campaign mode to conserve the lasers and prolong the mission). ICESat fulfilled its mission objective of a 5-year data record in 2008, and ceased measurement collection in October, 2009. 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. The success of the ICESat mission resulted in follow-on missions including: Operation IceBridge, an airborne campaign to continue select measurements from ICESat (IceBridge bridges the time gap in data collection between the completion of the ICESat mission and the future ICESat-2 mission); and ICESat-2, a space borne mission to once again provide global elevation measurements.

ICESat-2 is a Tier 1 Decadal Survey mission scheduled for launch in 2016. This mission builds on the lessons learned from ICESat to design a new instrument: the Advanced Topographic Laser Altimeter System (ATLAS) to provide high-resolution elevation data. The improved design is expected to provide measurements with greater spatial resolution and accuracy in identifying temporal changes in ice sheet elevation and sea ice thickness than ICESat. The measurements from ICESat-2 will also provide

information on changes in elevation over oceans and land allowing opportunities for cryospheric as well as lower-latitude applications. A preliminary list of mission products is shown below in table 1.

ICESat-2 Science Data Products

Product Number	Name	Short Description	Latency*
ATL00	Telemetry Data	Raw ATLAS telemetry in packet format.	Downlinked 8 times per day
ATL01	Reformatted Telemetry	Parsed, partially reformatted into HDF5, generated daily, segmented into several minute granules.	2 days
ATL02	Science Unit Converted Telemetry	Photon time of flight, corrected for instrument effects. Includes all photons, pointing data, spacecraft position, housekeeping data, engineering data, and raw atmospheric profiles, segmented into several minute granules.	2 days
ATL03	Global Geolocated Photon Data	Precise latitude, longitude and elevation for every received photon, arranged by beam in the along-track direction. Photons classified by signal vs. background, as well as by surface type (land ice, sea ice, land, ocean), including all geophysical corrections (e.g. Earth tides, atmospheric delay, etc…). Segmented into several minute granules.	21 days
ATL04	Calibrated Backscatter Profiles	Along-track atmospheric backscatter data, 25 times per second. Includes calibration coefficients for polar regions. Segmented into several minute granules.	21 days
ATL06	Land Ice Height	Surface height for each beam with along- and across-track slopes calculated for each beam pair. Posted at 40m along-track; segmented into several minute granules.	45 days
ATL07	Arctic/Antarctic Sea Ice Elevation	Height of sea ice and open water leads at varying length scale based on returned photon rate for each beam presented along-track.	45 days
ATL08	Land Water Vegetation Elevation	Height of ground including canopy surface posted at fixed length scale, for each beam presented along-track. Where data permits include canopy height, canopy cover percentage, surface slope and roughness, and apparent reflectance.	45 days
ATL09	ATLAS Atmosphere Cloud Layer Characteristics	Along-track cloud and other significant atmosphere layer heights, blowing snow, integrated backscatter, and optical depth.	45 days
ATL10	Arctic/Antarctic Sea Ice Freeboard	Estimate of sea ice freeboard over specific spatial scales using all available sea surface height measurements. Contains statistics of sea surface and sea ice heights.	45 days
ATL11	Land Ice H(t) Series	Time series of height at points on the ice sheet, calculated based on repeat tracks and/or cross-overs.	45 days from receipt of last data in product
ATL12	Ocean Elevation	Surface height at specific length scale. Where data permits include estimates of height distribution, roughness, surface slope, and apparent reflectance.	45 days from receipt of last data in product
ATL13	Inland Water Elevation	Along-track inland water elevation based on specific inland water mask. Where data permits, include roughness, slope and aspect.	45 days from receipt of last data in product
ATL14	Land Ice Gridded Height	Height maps of each ice sheet for each year based on all available elevation data.	45 days from receipt of last data in product
ATL15	Antarctica / Greenland Ice Sheet dh/dt Gridded	Height change maps for each ice sheet, 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	Polar cloud fraction, blowing snow frequency, ground detection frequency.	45 days from receipt of last data in product
ATL18	Land/Canopy Gridded	Gridded ground surface height, canopy height, and canopy cover estimates.	45 days from receipt of last data in product
ATL19	Mean Sea Surface (MSS)	Gridded ocean height product.	45 days from receipt of last data in product
ATL20	Arctic / Antarctic Gridded Sea Ice Freeboard	Gridded sea ice freeboard.	45 days from receipt of last data in product
ATL21	Arctic/Antarctic Gridded Sea Surface Height w/in Sea Ice	Gridded monthly sea surface height inside the sea ice cover.	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.

Table 1. Preliminary proposed products list for ICESat-2.

Data from the ICESat-2 mission will be provided to the public in hdf5 file format using common data structures. Many of the Level 4 (L4) products will be in raster format with interpolation between observations to provide a consistent layer for applications. Latency between data collection and L3/L4 product generation may be 30 - 60 days due to the data duration required (i.e. monthly products) and the need for ancillary data and processing time.

2.1.MABEL data simulator

The ICESat-2 project has developed an airborne instrument, the Multi Angle Beam Experimental Laser (MABEL) that is operating for specific campaigns collecting data that are similar to what will be produced by ATLAS. The MABEL instrument is not a replica of the ATLAS instrument, but incorporates many of the key features of ATLAS (i.e., number of beams, data density, etc…) and can be used to produce simulated ATLAS data with similar characteristics and responses. These data will be used to develop algorithms for ICESat-2 and to characterize data flows and loads for ground systems. MABEL flew its first data campaign over Greenland in March, 2012 and a second campaign over the East Coast of the United States in September, 2012. The data collected represent measurements over a diversity of surface features including land ice and sea ice, inland water, coastal ocean, and forested areas. The data will be used to develop a better understanding of the performance of ATLAS-like LiDAR data over different surfaces. The level 1 and 2 data from these flights is available to the public through the ICESat-2 website (http://icesat.gsfc.nasa.gov/icesat2/data/mabel/mabel_docs.php). The MABEL data are also being used by the SDT for algorithm development. Data collection campaigns are planned for MABEL throughout the development period for the ICESat-2 mission. These future missions will increase the pool of information available for the SDT to develop and refine their algorithms in preparation for launch. Data products derived from MABEL data will be made available to the community at the discretion of the SDT member leading the algorithm development.

3. ICESat-2 Applications Community

The objective of the applications program is to extend the use of ICESat-2 products into the management and decision making arena. This will be attained through the pursuit of the following primary goals:

- Engage science data product developers to understand the mission products
- Engage the science data user community to understand their needs in terms of data products, formats, etc.
- Engage the data distribution community to understand the capabilities of the distribution systems to provide data that the applications community can utilize
- Identify applications which could potentially benefit from the measurements that will come from ICESat-2
- Coordinate between these primary stakeholder communities to serve the applications community and broaden the user community for ICESat-2

One key to engaging the applications community is to make the use of ICESat-2 data products easier to understand by communicating the details of implementation. This can be accomplished either in the initial product design or on the distribution end by addressing data formatting and structure through tools at the distribution facility (the Distributed Active Archive Center or DAAC). The science data user community is likely to be able to use the data they need in the format produced by the science team and will additionally be interested in having the broadest amount of information on each product. The applications community is more likely to be interested in the higher level products (i.e. L3 or L4) which

are gridded map products. Further, the applications community will likely want "simple" (i.e. raster interpretations rather than bit fields) measures of data quality and integrity. ICESat-2 data will be distributed by one of the network of NASA sponsored DAACs. These facilities are tailored to specific user communities and have often developed tools for addressing their specific users. The ICESat-2 Applications Advisory Council can leverage this knowledge by engaging the distribution facility to coordinate the styles and formats available to the end users to maximize the usefulness of the final products without compromising the science data communities need for maximizing information in the products.

A significant challenge for the Applications Team is to help the project science team promote the primary mission focus while striving toward the goal of incorporating the community of potential into the community of practice. This challenge will be addressed through coordination with strategic partners and with specific implementation strategies discussed in the following sections.

4. Strategic Partners

To begin to define the community of practice for ICESat-2, we will work through partners and other organizations to identify interested individuals and institutions that should benefit from the use of ICESat-2 data products. We will focus efforts on the establishment of strategic alliances with key users of satellite remote sensing data within the federal government including the Department of Defense (DoD), US Department of Agriculture (USDA), National Oceanic and Atmospheric Administration (NOAA), the Department of Interior (DoI) and the US Geological Survey (USGS). The ICESat-2 Applications Working Group (AppWG) (see Section 5.2) will identify potential models, programs and processes that would benefit from ICESat-2 data in these agencies and develop partnerships to amend or improve these processes in preparation for the eventual availability of the data. State governments, non-governmental organizations, the private sector, and international partners can also benefit from these initial investments in the federal sector and can further be benefited through the future solicitations and working group activities. The ICESat-2 Applications Team will promote high visibility of the program prior to launch by ensuring that the positive results are publicized in peer-reviewed literature as well as online in newsletters and list-serves. This will enable the ICESat-2 mission to maximize its impact.

There are a number of ongoing missions that are collecting altimetry and Earth surface data investigating research questions regarding land ice, sea ice, ocean circulation, vegetation and many others. The following missions have been identified as potential partners for ICESat-2 applications:

- ICEBridge
    - Measures changes in ice sheets and sea ice
- Carbon in Arctic Reserves Vulnerability Experiment (CARVE)
    - Measures key areas in Alaska primarily looking at Carbon but also a variety of surface characteristics
- ECO-3D
    - Comprehensive measurements of vegetation structure, biomass, and carbon
- Mission applications programs for complementary future missions

- Soil Moisture Active Passive (SMAP)
- Global Precipitation Mission (GPM)

5. Applications Initiatives

As part of the applications program, we will connect with the community of practice through a number of different methods. An online listserv will be created where interested individuals and organizations can sign up to receive updates and information via email to receive notices of applications activities. The listserv will also serve as the announcement vehicle for the workshops, tutorials and other events planned by the mission and Applications Team. We will work to expand the community of practice for each product listed in Table 1. To do this, we will employ the following initiatives and activities.

5.1.Host Interactive Workshops, Focus Sessions and Tutorials

The Applications Team will host at least one workshop, focus session or tutorial per year. These events are designed to bring developers and users together to engage in dialogue on how products are used and what can be done to improve them.

Workshops are defined as meetings with a broad diversity of topics that will be widely announced, open to all, and will facilitate information dissemination to audiences with diverse interests. The format will be primarily formal presentations and focus on getting information out to a diverse group of individuals that cover many different areas of science and applications. Presentations will be given by the project science team, product developers and application developers. Cross-discipline dialogue will be encouraged by engaging the different communities in a single meeting. Following the workshop a report will be prepared and disseminated by the Applications Team.

Focus Sessions will be smaller events focused on specific topics or tailored to specific communities to provide detailed information about a connected group of products or applications. The format will include some formal presentations but also more interactive sessions where there will be direct dialogue between developers and data users. The tutorial is intended to give direct feedback to both the user and the developer on how the products will function and how they can be improved or better utilized.

Tutorials are multi-NASA decadal mission events designed to leverage innovation on how to best combine data sets from different missions with those of ICESat-2. These events are hosted by the end user group such as NRL or USDA but organized and managed by the ICESat-2 Applications Team. The format includes formal presentation on each mission's objective and product description and then transitions into open dialogs between the scientists and the end users. Panels sessions, thematic break out groups and exploratory discussion on new joint product development are the main focus for tutorial and intend to give opportunity for multi-mission data users to explore ways of developing a new products that will better utilized.

5.2.ICESat-2 Applications Working Group

The ICESat-2 applications project will establish an Applications Working Group (AppWG) with members of the ICESat-2 project science office, the SDT, and members of the community of practice. The purpose of this group is to:

1. Provide guidance to the Applications Team by identifying key needs for the mission or the applications users so this can be incorporated in the applications plans.
2. Direct interaction with users to provide information on the mission and to solicit information on how the mission can provide useful data to the community.
3. Identify venues for promoting the use of mission data in applications.
    3.1. The ICESat-2 mission was designed to satisfy science goals, the AppWG is intended to broaden engagement to incorporate communities of potential that may not have otherwise been aware of the mission products.
4. AppWG members should be strong voices or leaders within their communities. AppWG members can suggest, assist or host any of the following efforts of the Applications Team to expose non-traditional users to the potential of the mission.
    4.1. Workshops or tutorials
    4.2. Targeted telecons
    4.3. Podcasts or similar short web based media
    4.4. Introductory slide sets
    4.5. Side meetings/town halls at conferences

The Applications Team will identify 10-12 individuals to serve on the AppWG who will review our plans, help us make decisions, find contacts in new communities, and potentially host mission tutorials on their topics of expertise. Each member will serve for a two year term and will suggest replacement representatives when their term limit has been reached. We will have quarterly telecons and request input on applications deliverables as they are produced.

5.3.Early Adopter Program[2]

The ICESat-2 Early Adopter (EA) program will promote applications research to provide 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. ICESat-2 Early Adopters are defined as those groups and individuals who have a direct or clearly defined need for ICESat-2 data, who have an existing application, who have an interest in utilizing a proposed ICESat-2 product and who are capable of applying their own resources (funding, personnel, facilities, etc.) to demonstrate the utility of ICESat-2 data for their particular system or model. The Early Adopter will use preliminary data products that will become standard products for the ICESat-2 mission. The goal of the

[2] ICESat-2 applications Early Adopter program is adapted from the work of the SMAP applications program and Susan Moran, SMAP Science Definition Team applications lead

Early Adopter designation is to accelerate the integration of ICESat-2 products after launch of the satellite by providing specific support to Early Adopters who commit to engage in pre-launch research that will enable integration of ICESat-2 data in their applications.

Characteristics of the EA program are:

- The EA program is an unfunded activity formalized through an early data access agreement between the mission and the participating organization.
- Each EA will be partnered with an SDT member who is developing a product that they could use.
- The EA will receive access to developmental products and interaction with the product developer enabling them to understand and integrate the new products into their systems.
- The SDT member will gain a partner who can evaluate products and offer feedback from a functionality perspective as well as potential calibration and validation information.
- Products provided to the EA organizations will be derived from MABEL (the ICESat-2 airborne simulator) and should be similar in format and functionality to the anticipated products from the mission.

Early Adopters will be solicited through an informal call for proposals during calendar year 2013.

5.4.Cross Mission Development

ICESat-2, like most missions, is primarily a standalone mission that will provide distinct products for the user communities. In practice, the products from ICESat-2 may yield additional benefit by combining with information from other missions. Most decision-making applications utilize information from many sources and combine the information to produce a comprehensive management strategy. The Applications Team will identify complementary missions by engaging the project science team, Applications Working Group, and the SDT through direct feedback at workshops and tutorials. The missions may be current or future missions but will be identified by specific products that can be complementary to the products from ICESat-2. The Applications Team will identify the applications coordinator for these missions and develop cross mission activities that can include workshops and tutorials to facilitate communications between the different user communities.

5.5.Data Distribution and Tools

In the post-launch time frame the data from ICESat-2 will be distributed to users through the National Snow and Ice Data Center (NSIDC). The Applications Team will work with the NSIDC to ensure that the applications users' needs are met. The Applications Team will provide information gained in the workshops and through the EA program to the NSIDC to give insight into how the community of practice is likely to use the products. We will also work with the NSIDC to identify ways to enhance the usability of products such as providing data conversion tools, identifying complementary products, and possibly suggestions for bundling products together. The Applications Team will also volunteer to send a representative to participate with the NSIDC User Working Group which provides guidance on product selection and visibility.

6. Performance

The ICESat-2 Applications Team was assembled when the mission was in phase "B" which is the design phase. This has allowed the team to interact with the mission while the technical details and challenges are being worked out. This affords the opportunity to have a complete understanding of why the instrument is designed the way it is with tradeoffs necessitating design feature selection. This information is useful when explaining to potential applications users why the instrument functions the way it does. The success of the applications program should ultimately be measured by how much increased visibility and uptake of ICESat-2 data in decision making applications has occurred. The establishment of the Applications Working Group and the creation of the Early Adopter program will ensure the extended uses and applications of ICESat-2 data. Anticipated deliverables include:

- Annual progress report to be distributed to the mission and Applied Sciences program
- Workshop reports for each hosted workshop and tutorial
- Publications in both peer reviewed and general audience publications
- Final report summarizing the Early Adopter program with successes and challenges
- Professional reviews, before and after launch, to elicit, from the community, product requirements and to characterize the community of practice.

In addition to the above deliverables the Applications coordinator will continue to have regular meetings with the project science team, will participate in SDT meetings, and will interact with SDT members on an individual basis in support of the ICESat-2 mission.