

Melting Ice, Rising Sea Level Monitoring and Forecasting of the Coastal & Marine Environment ICESat-2 Focus Session

15-16 November, 2016

Co-hosted by NASA Short-term Prediction Research and Transition Center

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I. Introduction

This report describes the motivation for and key results of a focus session conducted on November 15 and 16, 2016 for the NASA Ice, Cloud and land Elevation Satellite-2 (ICESat-2) mission. The report seeks to document outcomes of the focus session and to synthesize the feedback obtained from participants regarding the potential utility of the planned land ice, sea ice, and ocean science data products for coastal and marine forecasting applications.

The focus session corresponds to one of a series of pre-launch outreach events designed for the ICESat-2 Applications program in which the primary goal is to allow for direct dialogue between the mission data developers and stakeholders to create a mutual understanding of the expected functionality of the science data products and their potential applications. The focus session aligns with the overarching applications goals to 1) expand awareness of the ICESat-2 mission and its data products, and 2) to provide different user communities with the opportunity to provide direct feedback to the ICESat-2 mission scientists on opportunities for using and leveraging the use of the planned science data.

The two-day meeting was co-hosted by the NASA Short-term Prediction Research and Transition (SPoRT) Center at the National Space Science and Technology Center in Huntsville, Alabama. SPoRT focuses on transitioning unique NASA and National Oceanic and Atmospheric Administration (NOAA) observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale. As a co-host of the meeting SPoRT was expected to play a key role in facilitating the dialogue needed to understand the weather user community needs and requirements with regards to new satellite remote sensing data and in expanding, through its partners, the overall community that the mission can reach in order to identify priority end uses of the data.

The focus session sought to provide a forum for discussion and exchange of ideas between the private sector, academe, government agencies, and international partners. The discussions focused on ways ICESat-2 can be used to inform topographic features relevant to forecasting; incorporated with other operational products at the NOAA National Weather Service (NWS), and scaled to address the specific data dependencies of current forecasting techniques.

The focus session was geared to stakeholders in the coastal and marine forecasting communities and open to anyone interested in learning about the functionality of the ICESat-2 land ice, sea ice, ocean and inland water science data products. A list of invitees was developed based on members of the ICESat-2 applications community, on participants to past ICESat-2 applications events (e.g. 2014 ICESat-2 Sea Ice focus session), and on members of ocean and coastal organizations (e.g. Consortium for Ocean Leadership, Sea Grant Association).

II. Focus Session Description

The ICESat-2 Melting Ice, Rising Sea Level Focus Session was held on November 15 and 16, 2016, in Huntsville, Alabama. The focus session was convened by the ICESat-2 Applications Team (Appendix A lists members of the team) and coordinated, as well as co-hosted, in conjunction with the NASA Short-term Prediction Research and Transition (SPoRT) Center. The Applications Team worked in consultation with ICESat-2 Early Adopter PI, Bradley Zavodsky of SPoRT, who not only facilitated planning of the event at the SPoRT center, but also facilitated engagement with and participation of SPoRT's collaborative partners in the focus session. One of these collaborative partners is the NOAA National Weather Service (NWS)

Weather Forecast Office (WFO) in Huntsville, which is also housed at the National Space Science and Technology Center, where SPoRT is located. The strategic location of the NWS Huntsville WFO provided an opportunity for participants to get a firsthand account of how NASA SPoRT transitions observations and research capabilities to the operational weather community and allowed for a unique chance to tour the WFO as part of the event. A web conferencing system, used for the duration of the focus session, allowed for remote access by participants joining from overseas or outside the continental United States, including participation by multiple remote participants from the NWS Alaska Region.

A. Goals and Process

The Melting Ice, Rising Sea Level Focus Session aimed to provide an in-depth description of the land ice and ocean observations planned for ICESat-2 and to identify how these observations could be used for forecasting of the marine and coastal environments. The primary goal was to create space for open dialogue on the functionality of the ICESat-2 data products and to understand and explore initial expectations and needs that participants had for new satellite data. A primary objective was to identify a set of potential applications based on the feedback that emerged as the ICESat-2 scientists clarified the expected capabilities of the ICESat-2 data products. The focus session also sought to explore current data fusion approaches and correspondingly to identify paths to incorporate ICESat-2 with different data sources. Another objective of the focus session was to identify possible strategic collaborations, including, as a long term objective, to identify participants interested in becoming ICESat-2 Early Adopters.

The workshop brought together a total of 36 experts—20 onsite and 16 remote participants (listed in Appendix C). The majority were affiliated with government institutions (24 participants); however, the focus session also included participants from universities (6 participants), from company/business entities (2 participants), and from non-profits (4 participants). A total of eight participants represented the ICESat-2 mission including Deputy Project Scientist, Tom Neumann, members of the Science Definition Team (SDT; Sinead Farrell – Sea Ice and Polar Oceans, James Morrison – Oceans, Mike Jasinski – Inland Water), and leads from ICESat-2’s Distributed Active Archive Center (Steve Tanner and Amy Steiker). Kaitlin Walsh of NASA Goddard Space Flight Center (GSFC) presented on behalf of SDT member Ben Smith (Ice Sheets). Sabrina Delgado Arias of Science Systems and Applications, Inc. (at NASA GSFC) chaired and coordinated the focus session on behalf of the ICESat-2 Applications Team.

The overall size of the meeting was appropriate for a focus session (20-30 participants)—the smaller of the outreach application events. The small size allowed for round-table discussions and feedback from everyone. Remote participation varied throughout the focus session with a number of participants joining occasionally throughout the day. In total, 474 people were invited to the focus session, including people outside the current ICESat-2 Applications community (521 members, October 2016). A prospectus for the meeting was developed and also sent to the whole ICESat-2 applications community and posted to the ICESat-2 applications website (<http://icesat-2.gsfc.nasa.gov/applications>). Speaker guidelines were also emailed by the Applications Team to all speakers in advance of the focus session with directions for a final slide to include preliminary perspectives on the following topics:

1. Synergistic opportunities for using the upcoming satellite observations
2. Expectations for how ICESat-2 could advance our understanding of processes related to our coastal and marine ecosystems, in addition to how they can better inform decision making at local and international levels, and
3. Any foreseen challenges in using the observations

B. Agenda and Format

The Melting Ice, Rising Sea Level Focus Session was a two-day event, which concluded with tours of the NWS Huntsville WFO and, by request of some participants, of the Severe Weather Institute – Radar and Lighting Laboratories on the campus of the University of Alabama in Huntsville. The focus session was divided into five parts with each part ending with a Q&A or discussion panel in order to maximize the opportunity of participant feedback. A final collaborative brainstorming session was held at the end of Day 2 to organize and create action items for ideas shared throughout the event. The agenda for the focus session can be found in Appendix D.

Joanne Terek of the Science and Technology Office at Marshall Space Flight Center opened the focus session with a discussion of drivers and needs for science-stakeholder dialogue in the broader context of national and NASA agency goals. This was followed by a welcome from Bradley Zavodsky of SPoRT who also described SPoRT center expertise in transferring NASA and NOAA observations to operational use by end user partners. An overview of ICESat-2 operations and current status of the mission, including schedule update and ATLAS instrument status was provided by Tom Neumann of NASA GSFC. Sabrina Delgado Arias, ICESat-2 Applications Coordinator, provided an update of ICESat-2 applications initiatives and discussed the intended goals (as outlined in Section A of this report), format and expected outcomes of the focus session.

The welcome session concluded with a remote presentation by Michael Kingston of the British Law Firm, DWF LLP and with a round-the-room discussion of initial expectations for the focus session. Michael provided context from the perspective of the insurance industry for harnessing ice knowledge and data in support of 1) best practices for operations in Polar waters and 2) of creating an Arctic-wide ice regime and forum for best practices for safer and cleaner marine shipping operations. The proposed Arctic Council Forum for Best Practice, aims to include a number of participants, including satellite agencies such as NASA.

Initial expectations for the meeting ranged from learning more about the ICESat-2 data products for specific applications (e.g. coastal bathymetry, snow and ice) and target communities (e.g. Alaska forecasters, indigenous peoples) to understanding, from the perspective of the mission, how to extend applications to the Polar community and better link with stakeholders.

Overall, the focus session sought to both inform the community on the mission functionality and receive feedback on requirements and synergistic opportunities for using the data. An overview of the remaining sections of the focus session is provided next.

Part II: Expected Functionality of the ICESat-2 Data

ICESat-2 mission representatives provided an in-depth description of the planned ICESat-2 land ice, sea ice and oceans data products. Participants expressed particular interest on latency, data coverage (e.g. understanding whether there are prospects to extend the land ice data product all the way to the coast), and sampling strategy. See Product Snapshots provided in Appendix E for a summary of the data product presentations.

Part III: Opportunities for Operational Use

Presentations were given on current efforts to transition satellite data to operations and included a description of pre-launch investigations being conducted by ICESat-2 Early Adopters. Discussions

centered on the possibility of both integrating the data into operations and using it for validation or verification.

Part IV: Information Accessibility

The National Snow and Ice Data Center (NSIDC)—ICESat-2's Distributed Active Archive Center (DAAC)—presented plans for ICESat-2 data management. This included a discussion of expected distribution and tools for on-demand analysis and a live-demonstration of current subsetting capabilities for ICESat Geoscience Laser Altimeter System (GLAS) data using Earthdata Search (<https://search.earthdata.nasa.gov/>). In preparation for the focus session, the NSIDC put together a brief survey to solicit feedback from participants on tool requirements (<https://www.surveymonkey.com/r/IC2userfeedback>), which it presented as part of the discussion.

Day 1 concluded with a case example on challenges of information accessibility for local indigenous communities in Arctic Alaska presented by Matthew Druckenmiller of Rutgers University and NSIDC. Matthew's presentation provided insights into local sea ice knowledge and use, with examples of past collaborations in the region. He also discussed foreseen opportunities and challenges for the utility of ICESat-2 data in terms of expected value of observations and ability to reach local users.

Part IV: Data-Fusion Initiatives

Day 2 presentations centered on discussion of opportunities and current initiatives for data fusion. As part of this discussion, ICESat-2 SDT lead for Inland Water, Mike Jasinski, discussed the Inland Water Height Data Product that also will provide near shore coastal surface elevations, and derived water characteristics tested using MABEL observations (Jasinski et al., J. Coastal Res., 2016). He also provided an overview of the Surface Water Ocean Topography (SWOT) mission (<http://swot.jpl.nasa.gov/>) and GRACE-FO mission (<http://www.jpl.nasa.gov/missions>).

C. Outcomes

This meeting provided an opportunity for participants to learn about the data products being developed for ICESat-2's global observations of Earth's oceans, sea ice and land ice. The focus session allowed mission scientists and application leads to establish new relationships with participants, build upon existing relationships, and identify potential strategic collaboration to advance the utility of ICESat-2.

A key outcome of the focus session was feedback from participants on data latency and the challenges of working operationally with large latency data. The latency for each of the planned ICESat-2 data products can be observed in Appendix B. Most all of the applications that were discussed during the meeting communicated that 45 days latency would allow mostly validation of other models or observations.

Specific outcomes of this focus session were:

- Identification of eight potential applications of ICESat-2 data in the context of marine and coastal forecasting described in Section III of this report. Five tables, shown in Appendix F, synthesize the feedback received from speakers regarding current data needs and gaps, opportunities and

limitations of using ICESat-2 and pathways to advance utility of the expected observations for the eight applications.

- A follow-on discussion between SPoRT, the NSIDC DAAC and NASA ICESat-2 is being planned for early 2017 to develop a process for collecting end-user requirements for reduced latency needs.
- Two whitepapers, described below, were drafted in preparation for the meeting and finalized based on discussions during the focus session. Whitepapers will be posted to the ICESat-2 applications website (<http://icesat-2.gsfc.nasa.gov/applications>) early 2017.
 - **How can ICESat-2 contribute to identifying and tracking icebergs in shipping lanes?** Lead: Molly Brown, University of Maryland. Whitepaper incorporates input from the International Ice Patrol, US National Ice Center, Norwegian Ice Service, and Arctic and Antarctic Research Institute (AARI - Russia).
 - **How can we support safe navigation in sea ice and food security for Alaskan subsistence hunters in a rapidly changing and less predictable Arctic?** Leads: Lisa Sheffield Guy, Arctic Research Consortium of the U.S.; Rebecca Heim and Helen V. Wiggins from the National Weather Service, Alaska Region.
- Two new nominations to the Early Adopter Program
- Plans for a new working group to develop a satellite-based fused bathymetric product using ICESat-2 and Landsat-8. UPDATE: On January 17, 2017, the Applications Team hosted a call with representatives of the USGS, NGS, USACE, NOAA and Oregon State University to discuss the formation of a **new satellite-based bathymetry mapping task team**. The task team will be chartered under the International Working Group on Ocean and Coastal Mapping (IWG-OCM).

III. Participant Feedback

In discussing their current research or operations, participants identified a number of gaps that ICESat-2 may help inform, as well as opportunities for using the data alone or in combination with other data sources. Some participants noted, in particular, scarcity of observations in the Arctic and the need for ice type discrimination. Participants also pointed out the need for bringing together different sources of data, strengthening partnerships, and improving the way information is packaged for end users. The open discussion during the last day of the focus session provided an opportunity for everyone to share ideas on potential strategic collaborations and pathways moving forward to advance capabilities for using ICESat-2 data.

We created five tables to organize and synthesize the information provided by speakers in the context of eight applications:

- 1) **Support for National Weather Service Operational Weather Forecasting in Alaska** - speaker: Brad Zavodsky, SPoRT
- 2) **Coastal Change Analysis and Mapping** - speaker: Christopher Parrish, Oregon State University
- 3) **Weather and sea ice conditions in Alaska for subsistence hunters, local communities, and marine resource managers** - speaker: Lisa Sheffield Guy, Arctic Research Consortium of the U.S.
- 4) **Arctic Collaborative Environment (ACE) Planning Operations** (ranging from emergency response to siting of infrastructure and other uses of Arctic territories) – speaker: John Walsh, University of Alaska Fairbanks

- 5) **Navy Forecasts/Nowcasts for NOAA and US National Ice Center Operations in the Arctic** - speaker: Michael Phelps, Jacobs, Stennis Space Center, MS
- 6) **NOAA/NWS Arctic Test Bed Sea Ice Services** (e.g. Alaska Fishing Industry, Arctic Marine Transport) – speaker: Nate Eckstein, Environmental and Scientific Services Division
- 7) **Shortfast sea ice topography mapping** – speaker: Mathew L. Druckenmiller, National Snow & Ice Data Center, CIRES, University of Colorado Boulder; Department of Marine and Coastal Sciences, Rutgers University; Study of Environmental Arctic Change (SEARCH) Sea Ice Action Team
- 8) **DOD Prediction in the Arctic** – speaker: Sinead Farrell on behalf Andrew Roberts and Wieslaw Masloski (Naval Postgraduate School).

These tables, shown in Appendix F, provide information on the following five areas: 1) existing sources of data, models/methods for analysis; 2) data requirements and gaps; 3) pathways to advance utility of ICESat-2; 4) opportunities for strategic collaboration; and 5) challenges for applying ICESat-2 data. Below we provide a summary of our findings for each of the aforementioned areas, reporting on any additional feedback received from participants (other than speakers).

A. Existing sources of data, models/methods for analysis

A range of data sources and approaches for data integration were discussed for each of the eight applications. These are synthesized in Table 1 of Appendix F. Sources of satellite imagery, to name a few, include Landsat 8 for bathymetry, imagery from the NASA/NOAA Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band for tornado and hail tracks forecasting, and Cryosat-2 observations for ice thickness validation/verification. Multiple sources of ground and air based observations were also provided. Current data integration approaches range from evaluating new datasets directly in operations or simulated operational environments via NOAA/NWS Arctic Test Bed mechanisms to developing multi-layered visualizations and analyses. Efforts to integrate local observations are also noted for a number of the applications with observations ranging from weekly outlooks in narrative form to observations obtained from science citizen projects (e.g. Local Environment Observer Network, <https://www.leonetwork.org/en/leo/about>).

B. Data Needs and Gaps

Having identified current data sources and methods for analyses, discussion naturally led to identification of data needs and gaps (see Table 2 in Appendix F). Lack of in-situ data, sparse observations and limited coverage were some of the key data gaps identified by participants. Large data gaps, for example, exist for nearshore observations in Alaska. Chris Parrish described large unsurveyed coastal areas along Alaska and observations dating back to the 1940s and pre-1900s for areas of the Alaskan North Slope. Sea ice data was a recurring need for most applications including a need for improved understanding of sea ice thickness and sea ice extent. ICESat-2 can help by providing observations in these data-poor areas.

C. Pathways to advance capabilities for using ICESat-2

Each speaker was asked to include a slide in their presentations to outline how their institution or application will use ICESat-2 data products (Table 3). Specifically, ICESat-2 was expected to be useful for:

- Aiding situational awareness, in the case the data could be provided in near-real time

- Verification of sea ice models (including operational models run and used by NOAA NWS and the Naval Research Lab)
- Mapping remote or inaccessible coastal areas
- Supporting airborne mapping projects by providing reference data
- Providing more detailed descriptive information and predictions of sea ice type and characteristics
- Informing planning operations
- Integration of ice thickness products with local observation networks

Some of the actions or pathways proposed to investigate the utility of ICESat-2 were data-fusion and leveraging existing partnerships to test ICESat-2 capabilities. For example, SPoRT plans to work with the NWS Alaska Ice Desk to investigate the Sea ice Height/Freeboard data products and to determine whether these could provide additional guidance for weather forecasting at the expected 45 days latency. The NOAA/NWS Arctic Test Bed also proposed working with SPoRT and its other satellite partners to bring new capabilities to its Alaska Sea Ice and Marine forecast programs.

Various ideas for data-fusion with ICESat-2 surfaced throughout the focus session, including a suggestion for fusing ICESat-2 with NOAA's interactive multi-sensor snow and ice mapping system (IMS) (Tarendra Lakhankar, NOAA-Cooperative Remote Sensing Science & Technology Center). Two other specific ideas discussed by speakers were:

- Satellite-based fusion approach for coastal change analysis using ICESat-2 and Landsat-8
- Using ICESat-2 in combination with models of precipitation and temperature (in NWS Advanced Weather Interactive Processing System) to visualizing rate of land ice melt

D. Opportunities for Strategic Collaborations

Participants described a number of ideas for delivery and expansion of ICESat-2 data utility that would make use of existing partnerships and programs among stakeholder organizations. These were discussed in terms of facilitating creation of value-added products, facilitating access and use of future ICESat-2 observations, and supporting new collaborative research and evaluation (Table 4). Some of these strategic collaborations, listed below, are being pursued as part of ongoing Early Adopter research (with current funding by the Early Adopter), while others are ideas that could be pursued with additional funding.

1. SPoRT coordinating with forecasters to develop value-added quantitative products using ICESat-2 to describe the amount of melt water entering hydrologic system
2. Delivery of ICESat-2 via Sea Ice for Walrus Outlook network (<https://www.arcus.org/search-program/siwo>)
3. Delivery of ICESat-2 data products displayed with other variables via the openly accessible Arctic Collaborative Environment (ACE) Joint Capabilities Technology Demonstration Program
4. Connecting ICESat-2 research community with NWS operations in Alaska within the NOAA/NWS Arctic Test Bed
5. Automated analysis technique for the Los Alamos sea ice model (CICE) will be shared via the CICE Consortium to enable easy use of ICESat and future ICESat-2 measurements in Earth System Models.

During the focus session, some of the participants also expressed interest in the Early Adopter program and with respect to taking part in a possible working group for a new satellite-based fused bathymetric product.

E. Challenges for Applying ICESat-2 Data

Participants articulated a list of challenges identified by speakers for using ICESat-2 (Table 5). SPoRT, for example, expressed not being clear as to how the data would look (thin lines versus a series of overpasses) and not being able to make physical sense of the MABEL data after reading and displaying it. SPoRT requires a clear understanding of the new data products in their communication with NWS forecasters and other collaborative partners. The focus session was specifically designed to address these kind of inquiries by enabling direct feedback and clarification from the mission.

Several participants stressed the need to better understand how to use the data products at the expected latencies and a few expressed severe limitations due to the latency for direct incorporation or operational implementation of the data. Operational users communicated that they would be comfortable using data with known, systematic errors if the latency could be reduced. Consensus of the operational participants was that data latencies of 14 days would be acceptable for many applications, but for real-time sea ice monitoring latencies of less than 2 days would be of most use. Some of the participants also made reference to constraints arising from data format (HDF5)—not being easy to understand or preferring the use of geotiffs and shape files for decisions. ICESat-2's 91-day repeat cycle also raised some concern for attempting to detect bathymetry at a time of good water clarity and to detect shortfast ice—no guarantee of leads or locally clear skies.

Appendix A. ICESat-2 Applications Team

The ICESat-2 mission applications program initiated in response to the 2007 National Research Council Decadal Survey for Earth Science, which identified development of applications of satellite data as a priority for all future space-borne missions. Since 2012, ICESat-2 application leads, working in concert with the mission, have been developing and implementing an applications program to improve understanding of how the global earth observations planned for ICESat-2 can be effectively used by different organizations within decision processes that lead to actions with direct societal benefits.

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 stakeholders to identify opportunities for using the new measurements in specific applications.

Table 1. ICESat-2 Applications Team Members as of January 2016

Role in ICESat-2 Mission	Members	Affiliation
ICESat-2 Program Applications Coordinator	Sabrina Delgado Arias	Science Systems and Applications Inc (SSAI), NASA's Goddard Space Flight Center (GSFC)
ICESat-2 Deputy Program Applications (DPA) Lead	Vanessa Escobar	SSAI - GSFC
ICESat-2 Program Applications Lead	Molly Brown	University of Maryland
ICESat-2 SDT Member (Hydrology) & 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 Program Applications Lead	Woody Turner	NASA Headquarters (HQ)

Appendix B. Description of ICESat-2 Data Products

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 normalized relative backscatter profiles at full instrument resolution (25 times per second for ~30m vertical bins). Includes calibration coefficient values calculated in 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 varying length scale. Where data permits, include estimates of canopy height, relative canopy cover, canopy height distributions, surface roughness, surface slope, 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	Sea Ice Freeboard	Estimates of freeboard using sea ice heights and available sea surface heights 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 and apparent reflectance.	45 days from receipt of last data in product
ATL13	Inland Water Body Height	Along-track inland water height extracted from Land/Water/ Vegetation product. 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.

Last Update: 02/24/2015

Appendix C. List of Participants

Name	Organization	Participation
Amy Steiker	National Snow and Ice Data Center	on-site
Angela Ottoson	National Ice Center	remote
Bradley Zavodsky	NASA/MSFC SPoRT	on-site
Christopher Parrish	Oregon State University	on-site
Claudia Carabajal	NASA GSFC	remote
Dean Gesch	USGS	remote
Frank LaFontaine	NASA SPoRT	on-site
Gretchen Imahori	NOAA	remote
Hugh Brennan	NASA's Jet Propulsion Laboratory	on-site
Jamie Morison	University of Washington	on-site
Joanne Terek	Marshall Space Flight Center	on-site
Joe Casas	NASA MSFC	on-site
John Walsh	University of Alaska, Fairbanks	on-site
Kaitlin Walsh	NASA GSFC	on-site
Kevin Fuell	NASA/SPoRT	on-site
Kristopher White	National Weather Service	on-site
Lisa Scheffield	Arctic Research Consortium of the U.S.	remote
Maciej Miernecki	University of Hamburg, Hamburg	remote
Mark Middlebush	NAVOCEANO Contractor/Vencore, Inc.	remote
Mathew Druckenmiller	Rutgers University & NSIDC	remote
Michael Jasinski	NASA GSFC	on-site
Michael Kingston	Marine Trade & Energy, DWF LLP	remote
Michael Phelps	U.S. Naval Research Laboratory	on-site
Nathan Eckstein	National Weather Service/ARH	remote
Paul Faeth	Cadmus Group	remote
Paul Meyer	NASA/MSFC - SPoRT	on-site
Rebecca Heim	NWS Alaska Region	remote
Renee Tatusko	NOAA	remote
Richard Burcher	National Research Council of Canada	remote
Sabrina Delgado Arias	SSAI-NASA GSFC	on-site
Sinead Farrell	University of Maryland	on-site
Stelios Mertikas	Technical University of Crete	remote
Steve Tanner	National Snow and Ice Data Center	on-site
Tarendra Lakhankar	NOAA-CREST Center, The City University of New York	on-site
Tom Neumann	NASA GSFC	on-site
Xingren Wu	EMC/NCEP/NOAA	remote

Appendix D. Focus Session Agenda



FINAL AGENDA

Melting Ice, Rising Sea Level Focus Session

Monitoring and Forecasting of the Coastal and Marine Environment

Hosted by the NASA Ice, Cloud and land Elevation Satellite-2 (ICESat-2) Mission & NASA Short-term Prediction Research and Transition Center (SPoRT)

November 15-16, 2016 | National Space Science and Technology Center, Huntsville, Alabama

Tuesday, November 15, 2016		
Topic	Speaker	Time
Meet & Greet, Coffee		
		8:00-8:20 AM
Focus Session Welcome & Logistics	Joanne Terek, Assistant Manager, Science and Technology Office, Marshall Space Flight Center	8:20-8:30 AM
Introduction & SPoRT Overview	Bradley Zavodsky, NASA SPoRT	8:30-8:50 AM
ICESat-2 Mission Design, Orbits Schedule and Data Products	Tom Neumann, ICESat-2 Deputy Project Scientist, NASA GSFC	8:50-9:05 AM
ICESat-2 Applications Overview & Perspective	Molly Brown, ICESat-2 Applications Lead, University of Maryland Sabrina Delgado Arias, Science Systems and Applications, Inc./NASA GSFC	9:05-9:20 AM
Channeling Communication & Ice Information: Proposed Arctic Marine Best Practice Information Forum	[Remote] Michael Kingston, Marine Trade & Energy, DWF LLP	9:20-9:40 AM
Brief around-the-room introductions, expectation setting and initial Q&A		
		9:40-10:00 AM
Morning Break		
ICESat-2 Sea Surface Height Data Product	Jamie Morrison, University of Washington, ICESat-2 SDT Member - Oceans	10:15-10:40 AM
Measuring Ice-sheet height with ICESat-2	Kaitlin Walsh, NASA GSFC, on behalf of Ben Smith, University of Washington (ICESat-2 SDT Member - Ice Sheets)	10:40-11:05 AM
ICESat-2 Sea Ice Freeboard Data Product	Sinead Farrell, ESSIC, University of Maryland, ICESat-2 SDT Member – Sea Ice	11:05-11:30 AM
Panel Discussion – Q&A expected functionality of the data		
		11:30-12:00 PM
Lunch (Group Order – Jason’s Deli)		
NOAA Arctic Testbed – transitioning new satellite datasets into operations	[Remote] Nathan Eckstein, Science and Operations Officer, NOAA National Weather Service	1:10-1:35 PM
Modeling and Observation of Land Ice and Sea Ice Extent to Support Forecasters in Alaska	Bradley Zavodsky, NASA SPoRT, ICESat-2 Early Adopter	1:35-2:00 PM

Tuesday, November 15, 2016		
Topic	Speaker	Time
Recent Improvements in the U.S. Navy's Ice Modeling Using CryoSat-2 Ice Thickness	Michael Phelps, Jacobs Technology, Stennis Space Center	2:00-2:25 PM
ICESat-2 Emulator for the Los Alamos Sea Ice model (CICE) to evaluate DOD sea ice prediction in the Arctic	Sinead Farrell, ESSIC, UMD on behalf of Andrew Roberts, NPS Oceanography	2:25-2:40 PM
Panel Discussion – Synthesis: potential for operational use; discussion on collaborating to bring ICESat-2 to NOAA/NWS Arctic Testbed		2:40-3:00 PM
Afternoon Break		
ICESat-2 User Data Management at NSIDC DAAC	Steve Tanner Amy Steiker, National Snow & Ice Data Center (NSIDC)	3:15-3:40 PM
Challenges of Information Accessibility – Local Indigenous Communities in Arctic Alaska, Case Example	[Remote] Matthew Druckenmiller, Rutgers University & NSIDC	3:40-4:00 PM
Q&A and Reactions to Case Example		4:00-4:20 PM
Closing Remarks – Day 1		4:20-4:30 PM
Wednesday, November 16, 2016		
Topic	Speaker	Time
Opening Remarks & Objectives for Day 2		8:30-8:40 AM
Integrating ICESat-2 with GRACE, Jason-3, & SWOT	Michael F. Jasinski, NASA GSFC, ICESat-2 SDT Member – Inland Water	8:40-9:00 AM
The Arctic Collaborative Environment (ACE): Data & Tool Integration for the Arctic Region	John Walsh, ACE Project Scientist, International Arctic Research Center, University of Alaska Fairbanks	9:00-9:20 AM
Sensor Fusion Approach for Coastal Change Analysis and Mapping	Christopher Parrish, Oregon State University	9:20-9:40 AM
Sea Ice for Walrus Outlook	[Remote] Lisa Sheffield Guy, Arctic Research Consortium of the U.S.	9:40-10:00 AM
Q&A Fused Products		10:00-10:20 AM
Morning Break		
Collaborative discussion/brainstorming: Intersection of ICESat-2 Capabilities and User Needs Feedback from Whitepapers Opportunities to incorporate ICESat-2, NWS products and other data sources Strategic collaborations		11:20-11:50 AM
Summary of Actions & Closing Remarks		11:50AM-12:00 PM
Lunch (on your own)		12:00-1:00 PM
Tour of SPoRT & Huntsville National Weather Service		1:00-2:00 PM

Appendix E. ICESat-2 Product Presentation Snapshots

A. Snapshot: ICESat-2 Land Ice Data Product

Presented by Kaitlin Walsh of NASA GSFC on behalf of Ben Smith, Applied Physics Laboratory, University of Washington (SDT Member - Ice Sheets)

ICESat-2 will produce an ice surface elevation product (ATL06) that enables determination of:

- (1) Ice-sheet elevation change rates to an accuracy of ≤ 0.4 cm/yr. on an annual basis
- (2) Annual surface elevation change rates on outlet glaciers to an accuracy of ≤ 0.25 m/yr. over areas of 100 km² for year-to-year averages
- (3) Surface elevation change rates for dynamic ice features to an accuracy of ≤ 0.4 m/yr. along 1km ground track segments
- (4) Resolution of winter (accumulation) and summer (ablation) ice-sheet elevation change to 10 cm at 25 km x 25 km spatial scales

The surface height is derived at a given point on Earth's surface at a given time relative to the WGS-84 ellipsoid. ATL06 heights represent the mean surface height averaged along 40-m segments of ground track, posted every 20-m, for each of ATLAS's six beams. Segments within adjacent beams are aligned to facilitate estimation of the across-track surface slope; they are also aligned from orbit to orbit so that subsequent repeat tracks give height estimates for nearly the same location on the surface, simplifying the estimation of height changes made through repeat-track analysis.

Perspectives on Future Work

- Understanding of ice sheet mass balance is critical to making forecasts of future sea level rise; ICESat-2 will be used to determine ice sheet mass balance and subsequent contributions to sea level rise
- Measuring dynamic changes in marine-terminating glaciers (in addition to elevation change of the ice sheets)
 - How can ICESat-2 improve our understanding of how these glaciers flow, discharge ice and contribute to sea level rise?
- Measuring changes in mountain glaciers
 - ICESat-2 strives to improve coverage in previously under-studied areas
 - How do changes in these areas affect local hydrology? Access to drinking water?
- Changes in permafrost
 - How are areas reacting to a melting subsurface, leading to localized subsidence?

B. Snapshot: ICESat-2 Sea Ice and Polar Oceans Data Product

Presented by: Sinead L. Farrell, University of Maryland (SDT Member - Sea Ice/Polar Oceans)

ICESat-2 shall provide **monthly** surface elevation **products** to enable, when sea surface height references (leads) are available and under clear sky conditions, the determinations 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.

Routine Products:

- Along-track sea ice height (ATL07, Level 3A)
- Along-track sea surface height (ATL07, Level 3A)
- Along-track sea ice freeboard (ATL10, Level 3A)

Gridded Products:

- monthly sea ice freeboard (ATL20, L3B)
- monthly sea surface height (ATL21, L3B)

Research Products:

- Along-track sea ice thickness
- Gridded monthly sea ice thickness

ICESat-2 sea ice product characteristics are slightly different compared to traditional altimetry. Retrieval algorithms for sea ice freeboard and thickness are being defined at this time.

Perspectives on Future Work

- ICESat-2 will acquire year-round data over the ice-covered oceans, which includes all types of surface and atmospheric conditions, different seasons and through seasonal transitions.
- Early products will be limited to seasons and locations where retrievals are reliable
- A routine ice thickness product (research product at this time) will depend on available snow loading estimates near launch: direct observations from airborne snow radar (e.g. IceBridge); reanalysis and model data; climatology

C. Snapshot: ICESat-2 Ocean Surface-Height Data Product

Presented by: Jamie Morison, University of Washington (SDT Member - Oceans)

Routine Products:

- Ocean surface height at varying length scales (ATL12, Level 3A)

Gridded Products:

- Gridded sea surface height – Open Ocean (ATL19, L3B)

ATL19 will be a gridded version of the ATL12 and ATL07 Sea Surface Height or Dynamic Ocean Topography (DOT = SSH – geoid height)

D. Snapshot: ICESat-2 Inland Water Height Data Product

Presenter: Michael Jasinski, NASA GSFC (SDT Member – Inland Water)

Routine Products:

- Along track open water surface height statistics for all inland water bodies, including estuaries and near shore coastal areas (ATL13). Along track resolution will range from 100 to 1000m. Also included will be subsurface penetration and ice on/off flag.

Gridded Products:

- Water body surface slope and aspect (ATL13) for along track strong beams.

Appendix F. Focus Session Feedback Tables

Table 1: Existing sources of data, models/methods for analysis

We Application	Existing Data Sources, models/methods for Analysis
Support for NWS Operational Weather Forecasting in Alaska	<ul style="list-style-type: none"> • Short-term weather forecasts: <ul style="list-style-type: none"> ○ Atmosphere: hyperspectral IR sounders; CrIS ○ Land Surface: LIS, NASA Soil Moisture Active Passive (SMAP); LIS data are used by forecasters to help with areal flood prediction ○ Lighting: ground-based Lighting Mapping Array ○ Disasters (tornado and hail tracks): Imagery from NASA/NOAA VIIRS DNB, ISERV ○ Rain rate: NASA GPM
Coastal change analysis and mapping	<ul style="list-style-type: none"> • Bathymetry from passive multispectral satellite imagery (e.g. Landsat 8) • Airborne maps: National Center for Airborne Laser Mapping and US Army Corps of Engineers – Cold Regions Research and Engineering Laboratory (USACE CRREL)
Weather and sea ice conditions in Alaska for subsistence hunters, local communities, and marine resource managers	<ul style="list-style-type: none"> • Integration of scientific information and local observations – combined summary of current conditions, ice and weather forecasts, remote sensing imagery, and local observations • Remote sensing data: NASA Aqua & Terra MODIS (visible and IR); SNPP-VIIRS (visible, IR, and day-night-band); Sentinel-1a and -1b (synthetic aperture radar) • Visible satellite imagery and SAR currently provide <i>quality</i> observations of sea ice position and concentration
Arctic Collaborative Environment (ACE) Planning Operations (ranging from disaster assistance to border security in Arctic territories)	<ul style="list-style-type: none"> • Multi-layered, geo-referenced visualizations of data from an extensive catalog of data sets and user-defined Arctic data • Integration of imagery, environmental observations, events and modeling results for use in the Arctic Region • Citizen science reports – LEO: local observation network
Navy Forecasts/Nowcasts for NOAA and US National Ice Center operations in the Arctic	<ul style="list-style-type: none"> • Ice Concentration: <ul style="list-style-type: none"> ○ DMSP SSM/I and SSMIS IC (25 km) have been assimilated into the Navy’s ice forecast systems ○ Developed a technique to assimilate AMSR2 (10 km) and NIC Interactive Multisensor Snow and Ice Mapping System (IMS) ice mask (4 km) ○ NAVOCEANO implemented AMSR2 and IMS products into ACNFS and GOFS 3.1 in February 2015 ○ VIIRS (750 m) IC testing underway at NRL • Ice Thickness: CryoSat-2
NOAA/NWS Arctic Test Bed Sea Ice Services (e.g. Alaska Fishing Industry, Arctic Marine Transport)	<ul style="list-style-type: none"> • Satellite: <ul style="list-style-type: none"> ○ Himawari 8, GOES-R, SNPP & JPSS ○ Partners: Geographic Information Network of Alaska, SPoRT, CIMSS, National Environmental Satellite, Data, and Information Service (NESDIS)

Table 1: Existing sources of data, models/methods for analysis

We Application	Existing Data Sources, models/methods for Analysis
Shortfast sea ice topography mapping	<ul style="list-style-type: none"> • Community observations • Ice trail maps for ice type discrimination and navigation • Electromagnetic ground conductivity mapping (EM31) for observing ice thickness distribution • Barrow sea ice radar
DOD Prediction in the Arctic	<ul style="list-style-type: none"> • Reginal Arctic System Model (RASM) – uses Los Alamos Sea Ice model (CICE); Naval Postgraduate School contributes to CICE development • New method for evaluating sea ice thickness using observed freeboard from ICESat • Spectral analysis of IceBridge freeboard track data

Table 2. Data requirements and gaps

Application	Data Requirements and Gaps
Support for NWS Operational Weather Forecasting in Alaska	<ul style="list-style-type: none"> • Sea ice guidance (daily/seasonal/inter-annual) <ul style="list-style-type: none"> ○ Sea ice extent for NWS Alaska Ice Desk – critical for offshore oil and commercial fishing • Sea ice modeling <ul style="list-style-type: none"> ○ Buoys are sparse and do not always measure ice depth ○ Much is unknown about errors in NOAA/NWS operational sea ice model • Glacier extent over long time scales (more than just nowcasting) • River outflow (can lead to catastrophic flooding) <ul style="list-style-type: none"> ○ Driven by melting of land ice – full understanding of extent and details of land ice depth accumulated each winter is not possible
Coastal change analysis and mapping	<ul style="list-style-type: none"> • Nearshore data gaps: <ul style="list-style-type: none"> ○ large areas “unsurveyed”—coastal “white ribbon” ○ Rows of charted depths reflect limited coverage of old survey methods ○ Most of Alaskan North Slope surveyed from 1940s to 1960s (even pre-1900 in certain areas!)
Weather and sea ice conditions for subsistence hunters, local communities, and marine resource managers (shipping and transportation)	<ul style="list-style-type: none"> • Integration Sea ice type and distribution (polynyas, open water leads) • Sea ice conditions for determining travel on or through sea ice: freeboard and concentration • Visible satellite imagery limited by cloud cover; SAR limited by geographic coverage • Interpretation of sea ice thickness • Improved observations of sea ice thickness to support Arctic community food-security and safety

Table 2. Data requirements and gaps

Application	Data Requirements and Gaps
Arctic Collaborative Environment (ACE) Planning Operations (ranging from disaster assistance to border security in Arctic territories)	<ul style="list-style-type: none"> • Primary categories <ul style="list-style-type: none"> ○ Weather (observations, analyses; satellite; forecasts); Ocean; Sea Ice; Snow; Terrestrial; Hydrology; Hazards; Infrastructure; Webcams, Miscellaneous
Navy Forecasts/Nowcasts for NOAA and US National Ice Center operations	<ul style="list-style-type: none"> • Improved sea ice thickness and ice concentration for the Arctic
NOAA/NWS Arctic Test Bed Sea Ice Services (e.g. Alaska Fishing Industry, Arctic Marine Transport)	<ul style="list-style-type: none"> • Model and data assimilation improvement to operational models for sea ice forecasting • Seasonal sea ice guidance • Coupled weather/water/ice modeling – weather, water, ocean, wave and sea ice forecasting continue to be incredibly challenging • Scarce Arctic in-situ observation network • Sea ice modeling capabilities far from mature • NWP performance: CONUS vs. OCONUS
Shorfast sea ice topography mapping	<ul style="list-style-type: none"> • Repeat shorefast ice extent observations <ul style="list-style-type: none"> ○ Ability to examine dynamic processes that drive changes in extent and topography (i.e. the accretion history) • Variations in shorefast ice thickness during Autumn freeze-up • Comparison with local observations and measurements • Mapped products of shorefast topography for communities
DOD Prediction in the Arctic	<ul style="list-style-type: none"> • Evaluating sea ice models using measured freeboard, with relatively well established bounds of error, is more desirable than using sea ice thickness derived from freeboard measurements. • Scale dependency exists at 30 km resolution or greater

Table 3. Pathways to advance capabilities for using ICESat-2

Application	Pathways to advance capabilities using ICESat-2
Support for NWS Operational Weather Forecasting in Alaska	<ul style="list-style-type: none"> • SPoRT will work with Ice Desk to investigate whether the ICESat-2 ATL07/10 (Sea ice Height/Freeboard) products could provide some additional guidance given current latencies (45 days) • ICESat-2 ATL07/10 at current latency (45 days) will be used to verify the operational sea ice model (at the Environmental Modeling Center) run by NOAA/NWS; SPoRT will work with Arctic Testbed to format data for verification • NRT ICESat-2 sea ice product could aid situational awareness by giving forecasters more confidence in modeled sea ice • SPoRT will take the ICESat-2 Land Ice product (ATL06) and format for ingest into NWS AWIPS for display with

Table 3. Pathways to advance capabilities for using ICESat-2

Application	Pathways to advance capabilities using ICESat-2
	<p>temperature and precipitation models (Note: rate of melt is determined by temperature and liquid precipitation that falls over land ice)</p>
<p>Coastal change analysis and mapping</p>	<p>Satellite-based fusion approach: ICESat-2 and Landsat 8</p> <ul style="list-style-type: none"> • Repeat Passes <ul style="list-style-type: none"> ○ ICESat-2: 91 day repeat cycle, 30-day sub-cycle ○ Landsat 8: 16-day repeat cycle <ul style="list-style-type: none"> ▪ Lots of possible attempts to catch area at a time of good water clarity ▪ Improve data density and signal-to-noise ratio through repeat coverage ▪ Facilitates change analysis • Allows to map remote or inaccessible coastal areas, e.g. coastal Arctic • Potential to support airborne mapping projects (NCALM/USACE CRREL) through reference data acquisition. • No data latency issues!
<p>Weather and sea ice conditions for subsistence hunters, local communities, and marine resource managers (shipping and transportation)</p>	<ul style="list-style-type: none"> • Provide more detailed descriptive information and predictions of sea ice type and characteristics – especially sea ice thickness • Validation/verification of sea ice models
<p>Arctic Collaborative Environment (ACE) Planning Operations (ranging from disaster assistance to border security in Arctic territories)</p>	<ul style="list-style-type: none"> • Use of ICESat-2 products to inform planning operations, ranging from emergency response to siting of infrastructure and other uses of Arctic territories
<p>Navy Forecasts/Nowcasts for NOAA and US National Ice Center operations in the Arctic</p>	<ul style="list-style-type: none"> • Prepare for testing with ICESat-2 <ul style="list-style-type: none"> ○ How to use data with latency of 30-90 days? ○ What is best technique to reinitialize and bring model system to real time?
<p>NOAA/NWS Arctic Test Bed Sea Ice Services (e.g. Alaska Fishing Industry, Arctic Marine Transport)</p>	<ul style="list-style-type: none"> • Working with SPoRT and other satellite partners to bring new capabilities to the Alaska Sea Ice and Marine forecast programs • Potential to evaluate new datasets directly in operations or in a simulated operational environment
<p>Shortfast sea ice topography mapping</p>	<ul style="list-style-type: none"> • Ice thickness (freeboard) products to integrate with local observation networks
<p>DOD Prediction in the Arctic</p>	<ul style="list-style-type: none"> • Automate analysis technique for CICE

Table 3. Pathways to advance capabilities for using ICESat-2

Application	Pathways to advance capabilities using ICESat-2
	<ul style="list-style-type: none"> Establish whether statistical relationships observed in the analysis with ICESat and IceBridge data are found to hold for real ICESat-2 freeboard

Table 4. Opportunities for strategic collaboration

Application	Opportunities for strategic collaboration
Support for NWS Operational Weather Forecasting in Alaska	<ul style="list-style-type: none"> In coordination with forecasters, SPoRT could develop value-added quantitative products to describe the amount of melt water entering hydrologic system
Coastal change analysis and mapping	<ul style="list-style-type: none"> Develop robust simulator for extending bathymetry retrieval to simulated ICESat-2 ATLAS data (University of Houston-Ohio State University partnership)
Weather and sea ice conditions for subsistence hunters, local communities, and marine resource managers (shipping and transportation)	<ul style="list-style-type: none"> Deliver information from ICESat-2 via existing SIWO network of indigenous and community users
Arctic Collaborative Environment (ACE) Planning Operations (ranging from emergency response to siting of infrastructure and other uses of Arctic territories)	<ul style="list-style-type: none"> Context: ICESat-2 products displayed with other variables [data would be openly accessible to researchers, students, search-and-rescue operators, native hunters, and others via ACE Joint Capabilities Technology Demonstration (JCTD) Program Use of supporting datasets, including local observer reports, for evaluation of satellite products for coastal sea ice thickness, sea level, and vegetation (with snow)
Navy Forecasts/Nowcasts for NOAA and US National Ice Center operations in the Arctic	<ul style="list-style-type: none"> 2 hindcast studies performed for March 15, 2014-September 30, 2015 <ul style="list-style-type: none"> ○ Initialized with CryoSat2-NASA ice thickness ○ Initialized with CryoSat2-ESA ice thickness Evaluations performed: <ul style="list-style-type: none"> ○ Ice thickness vs. WHOI Upward Looking Sonar, CRREL Ice Mass Balance Buoys, NASA IceBridge ○ Ice drift vs. International Arctic Buoy Programme ○ Ice volume vs. PIOMAS <p>→ Prepare for testing with ICESat-2</p>
NOAA/NWS Arctic Test Bed Sea Ice Services (e.g. Alaska Fishing Industry, Arctic Marine Transport)	<ul style="list-style-type: none"> Connecting the research community with NWS operations in Alaska
Shortfast sea ice topography mapping	<ul style="list-style-type: none"> ICESat-2 to support closer collaboration and act as basis for new collaborative research on shorefast ice stability and coastal processes

Table 4. Opportunities for strategic collaboration

Application	Opportunities for strategic collaboration
DOD Prediction in the Arctic	<ul style="list-style-type: none"> Automated analysis technique for CICE will be shared via the CICE Consortium to enable easy use of ICESat and future ICESat-2 measurements in Earth System Models. Code will be released about 3 months after statistical relationships established via analysis for ICESat and IceBridge data are found to hold for real ICESat-2 freeboard.

Table 5. Challenges for applying ICESat-2 data

Application	Challenges for applying ICESat-2 data
Support for NWS Operational Weather Forecasting in Alaska	<ul style="list-style-type: none"> Need for L2 geophysical proxy products <ul style="list-style-type: none"> Need MABEL data as geophysical parameters to be able to communicate what ICESat-2 products will look like to continue engagement with Arctic Testbed. Question: are there any proxy products (e.g. CryoSat-2) that could be used to begin engaging users? Latency of ICESat-2 L2 geophysical products at 45 days severely limits any sort of operational implementation of the data <ul style="list-style-type: none"> Forecasters typically want data with latency on the order of hours For slowly evolving processes (such as sea and ice height) latencies on the order of a week or even two may be acceptable even if this resulted in systematic errors in the location or amount of ice.
Coastal change analysis and mapping	<ul style="list-style-type: none"> 91-day repeat cycle: less possible attempts to detect bathymetry at a time of good water clarity HDF5 format constrains for decisions <ul style="list-style-type: none"> Geotiffs and shape files
Weather and sea ice conditions for subsistence hunters, local communities, and marine resource managers (shipping and transportation)	<ul style="list-style-type: none"> Direct incorporation of ICESat-2 information onto SIWO products – need frequent, location-specific information on an easy-to-understand format
Navy Forecasts/Nowcasts for NOAA and US National Ice Center operations	<ul style="list-style-type: none"> Latency: How to use data with latency of 30-90 days? What is best technique to reinitialize and bring model system to real time?
NOAA/NWS Arctic Test Bed Sea Ice Services (e.g. Alaska Fishing Industry, Arctic Marine Transport)	<ul style="list-style-type: none"> Limited staffing, often working on regional and national NWS projects Validation! How do great research ideas get to end users who need to make important decisions?
Shortfast sea ice topography mapping	<ul style="list-style-type: none"> Challenges for information accessibility <ul style="list-style-type: none"> 91-day repeat observations (no guarantee of leads or clear skies locally) Product latency

Table 5. Challenges for applying ICESat-2 data

Application	Challenges for applying ICESat-2 data
	<ul style="list-style-type: none"><li data-bbox="667 281 1398 348">○ Inability to resolve key features that local experts observe as indicators of local shorefast ice stability<li data-bbox="667 352 1398 413">○ Connectivity, bandwidth, and format barriers to reaching local user