Operation IceBridge

Response to Land Ice Group Mid-Term Review Recommendations

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Note: Recommendations from the Mid-Term Review Team are in black font and responses from the Project Science Office are in blue font.

General Recommendations and Response

Project Science Office Response

The Mid-Term Review Team has done an outstanding job in reviewing all science relevant aspects of Operation IceBridge and has come up with an excellent list of recommendations. Many of the recommendations are part of outstanding science questions in the field of glaciology and will require a much broader involvement of the science community as well as pooling of available resources in order to make significant progress on these issues. IceBridge can play a leadership role in some of these topics. However, IceBridge is a cost constrained mission, and available resources in terms of funding, personnel, and aircraft operations are already stretched thin. It is unlikely that additional funds will be made available for a cost constrained mission and therefore adding new tasks will likely require scaling back existing efforts or terminating them entirely. The Project Science Office agrees with all recommendations but is facing the reality of limited resources that are available to run the mission and take on new tasks. A growing concern from a mission management point of view is mission creep and the danger of losing focus on the main mission goals by trying to solve too many problems at once. With these constraints in mind, the Project Science Office, together with the IceBridge Science and Instrument Teams, NASA Headquarters and if necessary the science community will develop a prioritized plan over the next couple of months of which recommendations can likely be implemented.

Mid-Term Review Team Recommendations

The OIBMR-T has made several recommendations that would further strengthen the OIB mission as it moves into the second phase, summarized below:

- Revisit the science requirements so that the list is more concisely and clearly defined;
- Revisit flight-planning priorities to enhance the capabilities of OIB to act as a bridge between satellite altimetry missions and to allow for cross-calibration between the altimeters;
- Include additional instruments for retrieval of snow radiative transfer properties critical for characterizing scattering of 532nm wavelength laser altimeters and atmospheric forcing at the surface and for improved photogrammetric mapping of glacier topography;
- Publication of key review papers documenting the mission and its observing capabilities.

The discontinuation of OIB would leave a large gap the observational record of ice sheet properties required to further understand glacier and ice sheet response to external forcing and their consequence for sea level change. ***The OIBMR-T LIG recommends that efforts are made to secure funding for the continuation of OIB for at least the next decade.***

Response from Project Science Office

This is an issue for the program level at NASA Headquarters and is outside the control of the Project Science Office or project.

Response to Individual Sections of the Report

1. OIB Land Ice Goals and Accomplishments

Project Science Office Response: No specific recommendations were given in in this section.

2. Summary of IceBridge User Survey

Project Science Office Response: No specific recommendations were given in in this section.

3. Recommendations for further enhancing OIB outcomes

3.1 OIB Science Goals and Requirements

Mid-Term Review Team Recommendations

1) Revisit the land-ice science requirements and streamline them so that they are more concisely and clearly defined;

Project Science Office Response: The Science Team and Project Science Office agree with the recommendation of the review team. The IceBridge Science Team has been tasked to revisit the Level 1 Science Requirements and will do so.

Mid-Term Review Team Recommendations

2) Include the following new targets as aircraft logistics and NASA programmatic goals allow:

(i) selected ICESat-2 ground tracks on the ice sheets over a range of conditions i.e. elevation/melt/roughness; and

(ii) infrequent coverage of other large and rapidly changing non-polar glacier systems, especially when logistically straightforward.

Project Science Office Response: (i) The final ICESat-2 orbits have only been available recently and IceBridge has started flying future ICESat-2 orbits; for example: the ICESat and ICESat-2 cal/val site in the Dry Valleys of the Transantarctic Mountains, and near Summit Station in Greenland. We have also sampled several future ICESat-2 ground orbits over Greenland in Spring 2014. The Science Team has given a high priority to fly the ICESat-2 inflection point around 88°S at South Pole, but the government shutdown last year resulted in a shortened field season and prevented collecting data so far. It needs to be kept in mind that flying future ICESat-2 ground tracks poses a risk, a lesson learned during ICESat-1, when orbits were changed after launch. (ii) Since the start of IceBridge the Science Team has always considered flying opportunistic targets along transit flights (Alaskan glaciers, glaciers in South America), however, weather during transit flights and other constraints have not resulted in a large data set so far. The intention to do this has been there from the beginning and continues to be raised; the implementation, however, is often quite difficult and costly.

3) Re-evaluate the requirement to monitor the changing subglacial water distribution (‘warm ice’) from repeat radar, basal-echo-amplitude data.

Project Science Office Response: The Science Team and Project Science Office agree with the recommendation of the review team. The IceBridge Science Team has been tasked to revisit the Level 1 Science Requirements and is inclined to remove the requirement IS14 to investigate the changing distribution of sub-glacial water.

3.2 Altimeter validation and cross-calibration

Mid-Term Review Team Recommendations

The OIBMR-T LIG **recommends the implementation of coordinated and simultaneous validation campaigns on common and different platforms for altimeter cross-calibration, as follows**:

1) **Additional work should be done to ensure direct comparability between elevations retrieved from the different satellite and airborne altimeters.**

2) **Validation campaign for Greenland Ice Sheet in summer to sampled a variety of snow and ice conditions to quantify the volume-scattering bias, flying both a 532 nm and 1064 nm laser altimeter simultaneously, and an imaging spectrometer if possible.**

3) **Design targeted validation campaigns to quantify range uncertainties and biases for each of the OIB laser altimetry systems for glacier surfaces of varying roughness, slope and surface optical properties, and to better characterize the firn-densification process**.

To act on these recommendations, was suggested that OIB consider the coordination of a no-cost Announcement of Opportunity to support targeted field programs to improve altimeter cross-calibration.

Project Science Office Response

The issue of differences in penetration between green (532 nm) and infrared (1064 nm) laser altimeters has been discussed in the community for a long time. More recently the ICESat-2 Science Definition Team has put in two years of effort to better understand potential biases caused by penetration, which was one of the main reasons for the development of MABEL. MABEL has collected a large data set of simultaneous green and infrared measurements. The ICESat-2 SDT has concluded that the MABEL instrument is not calibrated and characterized to the extent necessary to make a definitive assessment possible. In addition, ICESat-2 is pursing lab activities using green and infrared laser light on well characterized snow samples (Tom Neumann, personal communication).

To put this issue at rest once and for all will require an effort that goes far beyond IceBridge. In order to eliminate other potential sources for biases such as differences in instrumentation and differences in surface retrieval algorithms, it is necessary to collect simultaneous data with a single instrument that will be processed in identical ways. In order to do this the ATM team has been tasked to develop a cost and feasibility estimate of modifying the future ATM T5 laser system to collect 532 nm and 1064 nm simultaneously. Depending on cost and feasibility it will be determined if this effort can be supported by IceBridge or not. If feasible IceBridge will coordinate with the IS-2 SDT and MABEL team to develop a joint plan. It will be challenging to design an experiment that will produce a definitive answer once and for all. It will likely require a significant amount of additional funding and resources to implement such an experiment.

3.2 Flight planning

3.2.1 Mechanism for soliciting input from broader cryospheric community

Mid-Term Review Team Recommendation

Recommendation: OIB adopt a more transparent method for selecting and coordinating land- ice flight lines during future OIB campaigns. An example would be to hold semi-formal planning meetings amongst PIs to discuss flight planning.

Project Science Office Response

Since the beginning of IceBridge in 2009, the ad-hoc and Science Team flight planning meetings have been held back-to-back with PARCA meetings once per year in order to provide the community the opportunity for input. Currently, there is no such mechanism for the Antarctic flights. Given the large number of nations involved in Antarctic research it will be a much more challenging task to establish a similar system. The Project Science Office does not think that limiting community input to IceBridge-funded PIs is the right approach. The PARCA model of wide community input has proven to be successful. When the first IceBridge team was formed in 2010 we had long discussions of creating a system for community flight requests through mini proposals. The large work load involved with this and the only marginal improvement was not considered worth the effort. It has been repeatedly made clear by NASA Headquarters that IceBridge is a directed mission. Project resources are available to meet Level 1 Science Requirements and mission goals, rather than support for individual PI-led projects. That said we also want to make sure we hear about the best ideas and don't miss opportunities to coordinate data collection with other projects in order to add value to measurements. The Project Science Office, together with the Science Team will create a section in the IceBridge science website with transparent guidelines (and deadlines) about community flight requests.

3.2.1 Balance between local (rapid dynamics) and regional data-continuity flight patterns.

Mid-Term Review Team Recommendation:

The OIB ST has taken the approach of identifying the most critical and/or scientifically relevant ICESat lines for surveying at frequencies determined by the temporal scale of change. Long-established, pre-OIB flight lines on and around outlet glaciers have been re-surveyed, maintaining those multi-decadal time series, while coverage in scientifically important areas, such as the northwest and southeast coasts of Greenland, have been greatly expanded.

There is, however, strong consensus that OIB has likely oversampled some outlet glaciers, and other rapidly changing regions at the expense of broad spatial measurements that are needed to characterize decadal to century timescale responses of the ice sheet and to determine regional-scale changes in ice sheet volume. **Recommendation: OIB should place more emphasis on acquiring broader-scale coverage.**

Project Science Office Response

This is a topic that has been discussed at length in science team meetings and keeps coming up. For Greenland we provide ice sheet wide coverage. For Antarctica we are simply limited by the bases of operation and aircraft capabilities. The issues of adequate sampling strategy is greatly debated at every science team meeting. Dh/dt coverage is only one of many complex Level 1 science requirements that feed into flight line planning. Providing bedrock coverage and bathymetry for ice sheet models is another once and there is also the view that the dense coverage over some outlet glacier provided by IceBridge is still not sufficient for higher order ice sheet models.

3.4 Instrumentation

3.4.1 Magnetometer justification

Mid-Term Review Team Recommendation:

The OIBMR-T LIG raised questions as to the benefit of routinely including the magnetometer in the suite of OIB instrumentation. After discussions with OIB scientists, it seems that the magnetometer makes the inclusion of new instrumentation more difficult because their installation requires a re-calibration of the magnetometer. The magnetometer has had relatively few downloads from NSIDC (<50) and, to our knowledge, there are no published results that use the data. We acknowledge the useful role it has in delineating sedimentary from igneous, metamorphic and higher density bedrock types in support of gravity data interpretation.

Project Science Office Response

The magnetometer and gravimeter are no longer flown on P-3 deployments to Greenland. We have only used the magnetometer for the Antarctic deployment with the P-3 last year, because of a lack of magnetic data over large parts of Antarctica. The cost of installing and operating the magnetometer is marginal compared to enormous value of getting magnetic data over hard to reach parts of Antarctica.

3.4.2 Addition of a 1064 nm laser altimeter

Mid-Term Review Team Recommendation: Characterization of the multiple-scattering bias over a range of ice conditions (Seciton 3.2) would require that both a 532 nm and a 1064 nm laser altimeter to be installed on the same platform. **Recommendation: a conventional 1064 nm laser altimeter with similar characteristics as the ATM be mounted on the same platform as the ATM during the suggested validation campaign.**

Project Science Office Response: See response in section 3.2.

3.4.3 Addition of a visible/NIR imaging spectrometer

Mid-Term Review Team Recommendation:

The surface energy balance plays a critical role in the mass budget of glaciers and ice sheets. One of the primary energy terms contributing to melt is the absorption of shortwave radiation, which is greatly modulated by surface optical properties (reflectance). OIB provides a unique platform to characterize the surface optical properties of snow and ice with low atmospheric interference. With minimal additional cost, OIB could include an imaging spectrometer that would allow for the simultaneous measurement of reflectance, surface effective grain size, and characterization of trace light absorbing impurities. Such measurements would also be highly valuable for determining the surface radiation budget and characterizing the snow optical properties relevant to the multiple scattering of laser altimeters. One instrument that is ideally suited for this application is NASA's Airborne Visible / Infrared Imaging Spectrometer (AVIRIS) that is already being flown over snow as part of JPL's Airborne Snow Observatory. Inclusion of such an instrument would greatly enhance the science outcomes of the mission. **Recommendation: include an imaging spectrometer (ideally AVIRIS) as part of the OIB instrument suite.**

Project Science Office Response

Since writing of the mid-term review report NASA Headquarters has initiated the ARISE (Arctic Radiation-IceBridge Sea & Ice Experiment) campaign in summer 2014. ARISE will measure spectral and broadband radiative flux profiles, quantify surface characteristics, cloud properties, and other atmospheric state parameters under a variety of Arctic atmospheric and surface conditions using a variety of imaging spectrometers and radiometers. IceBridge will participate in this new mission with the LVIS system.

We have also added an upward looking and downward looking spectrometer plus sky camera to the P-3 instrument suite since Arctic 2014. This was done at no cost because the small UAV instrument package had been developed by the ATM team for MIZOPEX, but was never deployed. The ATM team, together with the science team and members of the science community are currently developing a data product.

From a practical point it will be very difficult to add a sophisticated imaging spectrometer such as AVIRIS to the P-3 instrument suite because of space and weight limitations. Even if space and weight in an aircraft would be available, the cost of operating such a sophisticated instrument on a regular basis will be comparable to funding a single IceBridge instrument team, and would roughly be 10% of the total annual IceBridge budget. It will require either a significant amount of additional funding or cutting a major component of IceBridge and replacing it by an instrument that is not justified by the Level 1 Science Requirements, which makes implementation of this recommendation for routine IceBridge missions challenging.

3.4.4 Re-evaluate the Digital Mapping System (DMS)

Mid-Term Review Team Recommendation:

The DMS camera has proven to be more challenging than originally anticipated and very few elevation models have been derived from the data. This is in large due to unanticipated changes in the focal length of the camera system with changes in temperature. A post-acquisition independent bundle adjustment is of limited benefit as it is poorly constrained by a lack of across track imagery. Therefore, the construction of high accuracy DEMs require the ATM data for control. This means that the DMS is able to add additional resolution to the ATM elevation observations but without maintaining its independence. Replacement with a relatively inexpensive photogrammetric camera would remove many of the issues experienced by the DMS and would allow for independent and automated DEM and orthophoto production. **Recommendation: re-evaluate the inclusion of the DMS and explore the option of replacing it with a photogrammetric mapping camera with more stable lenses and camera properties.**

Project Science Office Response

The Project Science Office and Science Team are well aware of the issues with DMS imagery over land ice. However, the main justification for the DMS system comes from lead detection over sea ice, which works well. DMS is a NASA Airborne Sensor Facility and as such projects like IceBridge are only charged MPCs (mission peculiar costs) for deployments. Adding a dedicated photogrammetric mapping system will require funding and entire new instrument team which will not be possible for the cost savings of removing the DMS system from the instrument suite.

3.4.5 Addition of a low-frequency radar or seismic methods for improved bed retrieval

Mid-Term Review Team Recommendation:

Retrieving bed topography under crevassed, temperate and polythermal ice typical for southern Greenland and Alaska outlet glaciers, has continued to be a major challenge for the radar depth sounder that is currently flown as part of the OIB suite of instruments. The problem is significant enough that OIB might consider alternatives to the current flight radar system strategies. To overcome this, the OIBMR-T LIG **recommends that the OIB SDT explore the following**:

- low frequency radars, perhaps gaining insights from those successfully deployed in Alaska
- alternative methods, for example seismic and electromagnetic imaging methods; much effort has been made through NSF to develop innovative seismic instrumentations for measuring ice thickness, bathymetry and sub-ice sediment thickness.

Project Science Office Response

There has been significant progress on imaging challenging outlet glaciers since the writing of the mid-term review. CReSIS has developed new processing techniques that seem to be capable of detecting the bed in many of the Greenland outlet glaciers that had no bed picks previously. CReSIS is currently re-processing these data and will provide an inventory of which glaciers still have no bedrock coverage. The results of this effort will be used to guide future IceBridge bed mapping efforts. Furthermore, the group at UC Irvine/JPL has developed the mass conservation approach that provides novel capabilities in imaging the bed. Working together, the IceBridge Science Team, the UCI team and CReSIS are working on combining the radar imaging method with the new mass conservation approach to make the best use of all available capabilities.

Adding low frequency radars in dedicated aircraft/campaigns, or even conducting seismic campaigns is outside the scope of IceBridge. There are many programs available at NSF and NASA that are suitable for submitting proposals to support these kinds of activities in addition to IceBridge measurements.

3.5 Data Usability and Accessibility

Mid-Term Review Team Recommendation:

An OIB Data Management plan (DMP) was released in May 2013 that gives OIB data standards, including submission schedules, production, formatting and documentation. Data formatting and documentation is primarily the responsibility of the individual instrument teams, with the NSIDC responsible for compiling the provided information into a standard metadata/documentation format and posting the data for distribution. In addition, OIB has funded the creation of an interactive web data portal for browsing/locating OIB data. Due a large volume of recent deliveries to the NSIDC from the instrument team and reformatting to comply with new NASA standards (as described below), there is a significant back log in data and documentation availability on the NSIDC website. Therefore, the panel is unable to fully assess the data accessibility, quality and utility, data delivery schedule or the adequacy of the documentation, at this time and some of the recommendations below may be obsolete. **Recommendation: the OIB SDT conduct regular and frequent reviews of data usability and accessibility as these new products become available**.

Project Science Office Response: The Science Team is considering the possibility of conducting more formal reviews of data usability and accessibility. However, it should be pointed out that this is the responsibility of the Science Working Group (SWG) and we should avoid duplication of efforts.

3.5.1 Data Formatting

Mid-Term Review Team Recommendation:

Data formatting has presented a major challenge for OIB. OIB data have been distributed in a wide range of formats that are legacies of pre-OIB operations, and this practice continues today. Even some single datasets, such as the ATM QFIT data, are quite often inconsistently formatted between different campaigns (although we note that these data are being comprehensively reformatted as part of the NASA Earth Science Division (ESD) mandate, see below). The use of non-standard formats, some of which require specialized commercial software such as Matlab or IDL, poses a significant barrier to use. This has been one of the most easily identified, and significant, flaws in the OIB mission implementation to date.

NASA ESD has adopted new, stringent standards for data formatting (see https://earthdata.nasa.gov/data/standards-and-references/data-format-standards). According to the OIB DMP: “Operation IceBridge data product formats, with the exception of Level 0 or raw data, shall conform to one of the NASA ESD approved Data System standards.” While some instrument teams have embraced these formats, others plan to continue with their non- standard legacy formats, as given in the current DMP. This was facilitated by the fact that no data formatting standards were given in the OIB instrument team NRA.

While the OIBMR-T LIG recognizes that adopting new formats and reformatting old data represents a substantial, and largely unfunded, burden on the instrument teams, we consider that such standardization is essential and should be a priority for OIB, possibly through the granting of devoted funds to third parties and in collaboration with NASA data records programs such as MEaSURES and ACCESS. Such a formatting standardization is a worthwhile investment to facilitate use of OIB data and its long-term usefulness. This reformatting could be conducted as part of larger OIB data quality review. **Recommendation: OIB should set aside funds to ensure that all OIB data adheres to ESD approved Data System standards.**

Project Science Office Response: By the time of writing of this response the Project Science Office together with the instrument teams and NSIDC have developed a plan and timeline to convert all legacy data to the new formats. The necessary funds have been secured and format conversion and re-ingest at NSIDC should be completed by Spring 2015.

3.5.2. Data quality control

Mid-Term Review Team Recommendation: Data quality control has been the sole responsibility of the individual OIB instrument teams and data quality is inadequately documented. Importantly, there is no clearly-defined mechanism in place to ensure data conforms to the requirements. For example, in OIBMR-T LIG discussions the DMS L3 DEMs were repeatedly singled out as having particularly poor accessibility and documentation. DMS-generated elevation data is difficult to use, is only available in 2011, and has not been validated. Also, there is inadequate documentation about their generation. **Recommendation: the OIB ST should be tasked with ensuring that data providers/producers provide adequate quality assessments of all data products released by the OIB project**. Some specific recommendations should be formulated and implemented by the data experts themselves.

Project Science Office Response: In addition to the instrument teams, the Project Science Office and members of the Science Team contribute significantly to data quality control by working thoroughly with the data products. Furthermore, scientists in the community contribute to quality control in the same way. It is difficult to formalize this process since there is no substitute to scientists working with the data products. Work like this has revealed some minor issues with some data products that have been communicated to the instrument teams and have been addressed. Given that IceBridge provides over 60 data products to NSIDC we depend on the science community for quality control. The current model has been working well, but the IceBridge Science Team and the Project Science Office have agreed to think about establishing a more formalized process for quality control.

The lack of documentation for some data products is well known and NSIDC and the Project Science Office keep working the issue. In most cases limited resources on the instrument team side have delayed making documentation available. We have considered the alternative of delaying publication of data products until the documentation is available but consider this more harmful to the project than having a data product available that is currently lacking documentation.

Mid-Term Review Team Recommendation: Finally, the OIBMR-T LIG recommends that more effort be put into educating end-users on data use, such as webinars that discuss the collection of data by OIB, issues with the instruments, data formats and parameters. Although experienced investigators may be less likely to use these, they would be good tools for helping students get familiar with the data. Standardization of formats will have a multiplying effect: end-users themselves will more easily educate collaborators, and even potential new adopters of the data.

Project Science Office Response: NSIDC has been hosting such webinars and will continue to do so.

3.6 Reporting of OIB Results

Mid-Term Review Team Recommendation: Data collected by the OIB mission has resulted in an impressive number of high-quality and high- impact publications. There are, however, a lack of overview publications documenting the mission and its sensor capabilities that could stimulate a broader use of OIB data. The OIBMR-T recommends that the OIB ST initiate publication of key review papers documenting the mission and its observing capabilities.

Project Science Office Response: The Science Team is considering the possibility of review papers.