Landsat NEXT: Suggestions from GLIMS (Global Land Ice Measurements from Space) in response to an RFI

This report was prepared and submitted by Jeffrey S. Kargel with GLIMS community input

(A) User Feedback on Mission Science Requirements

ABOUT GLIMS: In this response to the RFI, I represent the GLIMS satellite data user community. Feedback incorporated here includes feedback from several GLIMS contributors. GLIMS (Global Land Ice Measurements from Space, www.glims.org) uses satellite observations to measure and map glaciers around the world, including their locations, numbers, key dimensional properties, surface flow speeds, vertical changes in thickness, and special situations such as hazards and contributions of glaciers to hydrogeology, hydropower, and water resources. Since inception in the late 1990's, hundreds of individual scientists and dozens of institutions have contributed data analysis results to GLIMS. There is no "membership," but we do have a Director (who now is Bruce Raup at NSIDC, and I was from 2003 to 2015), we maintain an Executive Board (which I continue to serve), the Executive Board includes Europeans closely connected to ESA and Sentinel-2, we maintain a formal NASA-supported glacier database at NSIDC, we have a mailing list with several hundred people on it, we generate group publications (Kargel et al. 2005, 2014; Raup et al. 2007, Armstrong et al. 2015, and others), and generally we function as a large but somewhat amorphous virtual research organization. We collaborate with other international glacier measurement initiatives such as the Randolph Glacier Inventory, and we advise U.N. committees and national climate assessments. GLIMS institutions secure their own funding, and contributions of data analysis results to the GLIMS glacier database or other contributions are entirely voluntary. Collectively, GLIMS members have generated hundreds of research publications, possibly half of which use Landsat data, many of them exclusively Landsat data.

USE OF LANDSAT DATA BY GLIMS:

The Landsat series provides the longest continuous satellite record of Earth's changing glaciers, and the improved quality and frequency of data acquisitions over the decades has made it one of the chief workhorses of GLIMS, along with ASTER, Sentinel 2 and, recently, commercial satellite data. Users commonly use anywhere from one to thousands of Landsat images in research publications. In one recent publication by my NASA-funded research group, for instance (Shugar et al. 2020), where we mapped glacial lakes worldwide, we made measurements using over a quarter million Landsat images.

Our uses of Landsat (and other satellite) data require imaging of snow and ice, rock debris, water (clean and turbid), and vegetation. Some of us look at snow and ice grain size, whereas others just want to know that it is snow and ice and to differentiate snow from coarser glacier ice. Most of us use visible and near infrared bands, and some of us use thermal bands, where, for instance, we are interested in mapping ice and snow where it is at the melting temperature. So Landsat data is in heavy demand by our organization.

The limits of Landsat have also caused most of us to also use other satellite data; for instance, many of us require stereo satellite imaging to map rugged mountain relief and changes over time in the thickness of glaciers, so we have also had a heavy reliance on ASTER. (In fact, GLIMS started out as an ASTER Science Team member project.) Some research requires higher spatial resolution provided by commercial imagery.

1. Suitability and/or desirability of the proposed Landsat Next Mission Science requirements, with reference to specific application areas. Provide any comments on the proposed new spectral bands, including their placement, proposed bandpass, spatial resolution, and radiometric requirements.

An informal set of recommendations submitted by me on behalf of GLIMS last June is now superceded by this document. It is duly noted that our highest priority recommended addition of sensor bands near 985 and 1090 nm, as recommended informally last June, has been adopted in documents linked within the RFI— approximately as we suggested— as bands 13a and 13b. In sum, GLIMS people are excited by the proposed set of spectral bands, and we find that the band specifications (pixel resolution, band width, radiometric sensitivity) are generally well suited to studies of snow and ice. We have one remaining major high-priority suggestion, which is not a wavelength band, but rather other cameras or mirrors, or whatever is needed to provided imaging parallax (stereo imaging).

HIGHEST PRIORITY ADDITIONAL RECOMMENDATION:

Consider adding a stereo band equivalent to ASTER band 3 nadir/aft pair to provide continuity from ASTER. Replication of ASTER Band 3 stereo we consider to be minimalistic. This suggestion is separate from and in addition to the Landsat NEXT RFI's suggestion of a 60-m resolution cirrus and aerosol band, which is needed for separate reasons but would not provide the topographic information that glacier studies need. We call for a dedicated topography stereo band— choose any VNIR band, and give it 10 or 15m/pixel resolution. 10m/pixel would be a marked improvement over ASTER's 15 m. Which band is chosen is not crucial, but SLI band 8a would be a possibility most closely matching the ASTER Band 3 stereo pair. GLIMS glacier studies have benefited enormously from the availability of vertical change information from ASTER band 3 stereo. We understand that this would entail a large engineering impact on Landsat NEXT, but the benefit would be shared broadly across the Earth sciences. Nothing flying internationally competes very well. We recommend a base angle between 30 and 45 degrees— an increase over ASTER (27.7 degrees), thus giving increased parallax. We do not recommend anything greater than 45 degrees, as this would excessively pick up hazes, and it would also put much mountainous terrain out of view due to the slopes. A novel consideration would be to have a stereo system with nadir, aft, and forward viewing cameras, either on one or as many as three platforms. Possibly leave a main platform as nadir-only with many spectral bands as Landsat NEXT currently envisions, plus have a single separate platform dedicated to stereo imaging, 27.7 degrees fore and aft, exactly like ASTER, but fore as well as aft. They could image simultaneously and gather information on sea state, canopy height, clouds, and— for glaciers— improved mountain topography that would capture north as well as south sides of steep mountain topography, north and south sides of glacier ablation pits, and so on.

2. Discuss the importance/desirability of four potential changes to the requirements:

a. Increasing the spatial resolution of the shortwave infrared (SWIR) 1 band (1610nm) from 20-meters to 10-meters (note that this may result a lower SNR requirement at 10-meter resolution)
10 m in this band would mark a major improvement from the pre-2008 ASTER (before failure of its SWIR instrument), which had 30 m/pixel in band 4 very near 1610 nm. Prior to failure of SWIR, Band 4 on ASTER (together with VNIR bands 1, 2, and 3) was used by almost everybody who was doing glacier mapping. Reduced SNR would be acceptable, because (1) the variations of snow reflectance at this wavelength is so extremely dependent on snow grain size that strong contrasts of reflectance with respect to rock, and within snowfields due to grain size variations, will be strong. Furthermore, for coarse glacier ice, reflectance is so low in this band, that the power of this band to discriminate ice from rock or other materials is by virtue of almost no photons leaving the ice, unlike the case for rocks, which we want to distinguish. We can deal with low SNR. The smaller pixel size (better spatial resolution) will be worth the tradeoff in SNR.

b. Adding a midwave infrared (MWIR, 3.9 micrometer) band to support active fire detection, mapping of volcanic activity, and measurement of fire radiative power. Discuss the specific benefits provided by a 3.9 micrometer band in addition to the existing shortwave and thermal infrared bands
Whereas the fire/volcano band would address some urgent public and scientific needs, GLIMS has little use for this proposed band in global glacier mapping. However, an expected important local use would be in areas where glaciers overlie volcanoes or are contacted by lava flows and there is a potential extreme hazard due to a potential for explosive eruptions or generation of lahars (mud and debris flows). This is common, for instance, in Iceland, parts of Alaska, and New Zealand. Famous, terrible disasters have happened due to glacier-ice interactions in New Zealand Colombia, and Mount Saint Helens, for instance, among many other places, collectively killings tens of thousands of people in the past hundred years. In recent years volcano-ice interactions have produced exceptional aviation hazards, for example in Iceland (effects felt in transAtlantic commercial aviation) due to the eruption of a volcano through a glacier.

c. Adding a small, off-nadir (along-track pointing) camera covering the visible spectral region at 60m resolution to improve cloud and aerosol mapping.
Clouds and aerosols, while meteorological phenomena, are important in GLIMS for four reasons: (1) They can obscure glaciers, and sometimes it can be hard to discern low level clouds or fogs from snow, so this can hinder accurate mapping. We rely on accurate cloud detection. (2) Thin cirrus, while sometimes not interfering with glacier mapping, can cause errors in on-ground snow and ice grain size mapping or mapping of melt zones on glaciers. (3) Clouds and high-altitude aerosols are important in mountain meteorology and climate, hence, in glacier mass balance. (4) High-altitude pollution aerosols and dust can be deposited on glaciers, and this can affect glacier melting and mass balance. For these reasons, improved cloud and aerosol detection are important to GLIMS. 60 m resolution would be sufficient to address these matters. *However, GLIMS has two other extremely important uses of stereo imaging, but both of these require resolutions much better than 60 m:* (i) to make better maps of mountain topography, which in

some places is not very good with existing satellite images and DEMs due to image saturation or too-steep topography. (ii) Most important, and really crucial to GLIMS's ability to measure glacier mass balance, we need to measure changes in surface elevation (changes in thickness) over glaciers over time. ASTER has been crucial for this, but 15 m is just marginally adequate—we generally need decadal changes to accumulate in order for ASTER's stereo imaging to be good enough for quality measurements of thickness changes, which are commonly around 40-100 cm/year lowering of glacier surfaces. 10 m stereo (and parallax like ASTER's, or slightly greater) in any visible band would mark a major improvement, or 15 m (like ASTER) but increased parallax would be an improvement. We also emphasize that too wide a base angle, like 60 degrees as somebody suggested, as far too high for good topographic mapping— that would pick up the hazes and reduce ground resolution. Something below 45 degrees but more than ASTER 27.7 degrees would help. So we see the proposed low-res cloud/aerosol band as important, but we don't want that to be construed as having satisfied one of the most important recommendations by GLIMS: to have a high resolution stereo band for topographic mapping of land, snow, and ice surfaces.

d. Adjusting the equatorial crossing time from 10:00am to 10:15am, which would better align with the Sentinel-2 crossing time of 10:30am, but deviate slightly from the historic Landsat crossing time

There would be no large deleterious or helpful impact for GLIMS. There are many small pros and cons of making the 15-minute shift, but they are all small, and they might balance out:

Con: (1) Mountain weather in places like the Himalaya commonly causes cloud cover to build up and spread from valleys to higher glacier elevations through the morning, and it can happen very rapidly. So going much later would have large adverse effects in such regions, but 15 minutes later is not likely to be a big problem. (2) A higher sun can make small topographic undulations on ice sheet surfaces less visible. (3) Shifting away from the past Landsats' orbits makes direct comparisons less perfect.

Pros: (1) In some places, morning fogs are a problem for imaging maritime glaciers, such as in coastal Alaska, and they can lift and then clear up through the morning, so later can be better. (2) Light night-time snow dustings (which can obscure what we want to see on glaciers) can melt or sublimate off through the morning, so in that sense later can be better. (3) 10:15 is closer to Sentinel-2 and also accords with Terra ASTER's orbit, so this would aid direct comparisons. (4) For Arctic and Antarctic studies, 15 minutes later for some dates can make a helpful difference in being able to see glacier and ice sheet surfaces for some dates, versus not (a matter of being illuminated by the sun or not in spring and fall).

All in all, a 15-minute change of Landsat NEXT's orbit's equator crossings is not crucially good or bad for GLIMS, and small pros and cons may balance out. Therefore, GLIMS takes no position on this.

3. Discuss the synergistic use of Landsat Next and Sentinel-2 (or other international or commercial) data, and the ability of an international “virtual constellation” to meet user desire for more frequent observations. Identify any improvements in mission operations or data products that would support combined use of these systems.

Possibility for an anomalous event detection system:

GLIMS is a heavy user not just of Landsat data, but many— dozens— of other satellites’ data. In the old days, not long ago, a heavy reliance on ASTER was limiting and commonly even painful. Some glaciers exposed to frequent cloud cover were imaged well just once or twice in all of ASTER’s two decades of operation! Most areas received one good image per two or three years, and only in a few places did we get two or three good images per year. Landsat 8 and Sentinel 2 have completely upended this problem. Now we have incredible high frequency of acquisition, to which commercial imaging adds.

So, how can we make better use of these data? Landsat NEXT’s strengths relative to commercial imaging and even Sentinel 2 may include— if our recommendations are implemented— a greater ability than ever before to measure snow and ice grain size, which can have benefits for glacier studies but also snow studies anywhere, on or off glaciers. The vegetation community may have similar needs and abilities to see changes in photosynthetic pigments, and GLIMS also has some interest in that (to see vegetation development on stagnating debris-covered glaciers in Alaska, for instance). Water studies (which GLIMS also does with glacial lakes) could benefit from products that measure changes in water quality, whether from suspended sediment or phytoplankton or organic pollution films. Hence, products that show changes relative to images on preceding anniversary dates, and seasonal changes, would be helpful. It’s a lot of data and a lot of data processing and archival that would be needed, but the suggested products would be used. Change detection can then establish, over some years, the normal seasonal changes or a normal range of interannual changes, versus an anomalous change. For example, glacier surges (large, sudden, and months-long increases of glacier flow speed) are commonly conditioned by large changes in the basal hydrology of glaciers, and many surges are attended by large shifts in the turbidity of rivers or lakes that the glaciers drain into. Surges themselves can build up over a period of months or years, so there may be an anomaly tip off of bigger things to come. These surges can be extremely hazardous, with roads or pipelines, bridges, or even towns that can be overridden. Landslides onto glaciers also are a big issue, as they can cause changes in the behavior of glaciers. Snow avalanches, likewise, are a problem and also a glaciological fact and deadly hazard in many regions. Glacier lake outburst floods, both big and small, can be devastating. These dynamics sometimes have precursory events, which Landsat NEXT might detect, especially if an automated system is in place to discern (and issue an alert to scientists) an anomalous versus an ordinary change. Hazard dynamics can also require follow-up. So what may be envisaged is a robust change detection system, with alerts provided where changes seem to be out of the ordinary. Esatblishing a baseline of ordinary seasonal and interannual changes may require many years to establish, but by the end of a decade, it could be in full operation. Anomalous changes seen by Landsat NEXT then could alert other imaging systems— perhaps automatically, or perhaps by scientists’ intervention— to begin intensive imaging.

4. Discuss improvements in USGS data products, archive, or delivery that you would want to see in the Landsat Next era.

We like what NASA/USGS/Landsat has been doing: Lots of free, easily accessible data.

(B) Feedback on Instrumentation Solutions

NASA and USGS wish to obtain feedback from industry and other space system providers on the feasibility of Landsat Next requirements, and the optimal instrumentation for meeting those requirements. Respondents to part B should identify their organization and provide a brief statement of background.

We are generally not instrument developers, so we primarily abstain from this part of the RFI. However, a major recommendation by GLIMS that would impose large changes in the Landsat NEXT instrumentation or mission architecture, is to add a *robust high-resolution stereo imaging capability* at least comparable to ASTER's, and ideally improved, as suggested above.

(C) Mission Architecture Approaches

NASA and USGS are interested in feedback pertaining to the overall mission architecture, including feedback on constellation versus single-platform approaches for meeting mission goals. Aside from the obvious benefits of putting our eggs in multiple baskets (different platforms), we think that possibly a multi-platform approach could be the simplest way to achieve high-parallax, high-spatial resolution (10 m) stereo imaging s briefly mentioned above. However, we just want stereo imaging of topography (not the same as the cirrus/aerosol stereo imaging band that the RFI mentions), whether or not it is on one or more platforms.