LiDAR and Height Modernization Workshop – Final Report

National Height Modernization Program
NOAA's National Geodetic Survey
Silver Spring, Maryland
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Introduction

The National Geodetic Survey's National Height Modernization Program (NHMP) hosted a 1-day LiDAR and Height Modernization Workshop in Silver Spring, MD on August 18, 2011. Over 60 partners and users from federal and state agencies, universities, and private industry participated in the workshop, and many more watched the presentations via an online webinar.

The NHMP has been working with local agencies and academic institutions across the country to improve their capacity to use new technology to derive accurate heights referenced to the National Spatial Reference System (NSRS). With improved geoid models, Global Navigation Satellite Systems (GNSS) like GPS can be used to measure heights to 2 cm accuracy. Accuracy of digital geospatial data collected with new remote sensing technologies has also improved in recent years. Products and activities that need accurate digital elevation data, like national DEMs, floodplain maps, hydrologic modeling, and coastal inundation studies, are relying more on LiDAR surveys.

Background

Several things converged to create an interest from the NHMP in holding a workshop on the use of LiDAR technology to obtain accurate heights. For example:

- Drs. Gary Jeffress (TX) and Roy Dokka (LA) expressed concern in recent years about the quality of LiDAR data used by FEMA to create their flood maps.
- Other NHMP partners voiced concern over the way QA/QC is done on LiDAR data collection, and how to define accuracy requirements for various applications.
- Numerous initiatives have been attempted or are ongoing to create a national elevation model or map with the help of LiDAR technology.

In her opening remarks, Juliana Blackwell, Director of NGS and former manager of the Height Modernization Program, talked about benefits of having accurate heights. She mentioned the range activities that rely on accurate elevation data, including transportation and engineering projects, floodplain mapping, and monitoring effects of crustal motion and climate change. She also reflected on the progress the Height Modernization program has made, leveraging GPS technology to measure accurate heights. Ms. Blackwell then remarked that while heights measured using LiDAR technology cannot yet achieve the accuracy that leveling and GPS surveys can reach, it has the distinct advantage of being able to capture a lot of data over a broad region in a relatively short amount of time, and capture height data that is valuable for numerous applications. Still, that data is only valuable if tied to reliable vertical control on the ground, and if standards for collection, processing, and QA/QC of the data are available. These challenges do not diminish the potential to use LiDAR to collect accurate elevation data, and many states are already using LiDAR successfully.

The audience for this workshop was primarily the NGS Height Modernization partners, but it was also opened to others who share similar interests or have similar questions regarding LiDAR. Goals of the workshop included:

- Learning about various applications using LiDAR data, and their vertical accuracy requirements.

- Learning about the National Enhanced Elevation Assessment (NEEA) being performed by the U.S. Geological Survey (USGS) to evaluate requirements of federal or local agencies and private industry.
- Identifying NGS' role with respect to both remote sensing and geodesy in improving the application of LiDAR technology in determining accurate elevations.

To accomplish these goals, the workshop had two main components. The morning session included presentations from LiDAR experts that introduced the technology itself, strategies for tying to geodetic control and QA/QC procedures for specific applications, and the National Enhanced Elevation Assessment (NEAA). The afternoon session was more interactive with a break-out session to discuss issues in acquiring or using LiDAR data and a panel discussion to address any remaining topics.

Presentation summary

"LiDAR 101" Dr. Christopher Parrish National Geodetic Survey	*Dr. Parrish introduced basic LiDAR terminology, science, principles, and history of the technology's development. He highlighted types of calibration, QA/QC, accuracy assessment, and the current ASPRS guidelines.*
"Accuracy requirement in coastal applications" Dr. Kirk Waters Coastal Services Center	*Dr. Waters explained why LiDAR can be suitable for mapping shoreline and sea level rise, discussed why accuracy requirements for sea level rise are not always obvious, and highlighted why mapping standards may not be the only way to look at uncertainty.*
"Quality Control of LiDAR" Mr. Gary Thompson North Carolina Geodetic Survey	*Mr. Thompson focused on North Carolina's quality control process to validate its LiDAR data to ensure it could be used for floodplain mapping. The Quality Control Surveys included GPS, traditional traverse, and leveling.*
LiDAR Data for Corridor Work Mr. Ken Sorrels Tuck Mapping Solutions, Inc.	*Mr. Sorrels explained that a scope of work will specify required accuracy (both horizontal and vertical), required datum for delivery, and who will provide control. He also discussed acquiring, post-processing, and validating LiDAR data, focusing on high density data collected by helicopter.*
"Green, Waveform LiDAR" Mr. Amar Nayegandhi Jacobs Technology – USGS	*Mr. Nayegandhi explained why blue-green wavelength LiDAR is used in all airborne bathymetric and "topo-bathy" systems. He also described why airborne bathymetric (subaqueous) LiDAR is of high value in filling the "0 to -10 m" depth gap in coastal mapping.*
National Enhanced Elevation Assessment (NEEA) Dr. David Maune, Dewberry Mr. Greg Snyder, USGS	*Mr. Snyder introduced the NEEA describing the project partners, stakeholders, purpose, and idealized timeline. Many groups have already contributed to an enhanced elevation data inventory, including LiDAR, photogrammetry, and interferometric synthetic aperture radar (IFSAR)* *Dr. Maune focused on topographic data quality level requirements and the frequency elevation data must be updated with respect to specifically identified business uses. The next part of his analysis will estimate costs, evaluate technology trends, identify risks, and develop implementation alternatives. The final report is due to USGS by December 15, 2011.*

Break-out session summary

During the break-out sessions, groups brainstormed lists of opportunities and challenges based on their experiences with or understanding of airborne LiDAR technology. Then each group ranked its top three issues that most need to be addressed. After combining similar issues, the list of nine challenges below reflected what participants at the workshop viewed as priority challenges.

Top challenges facing users of LiDAR data (*list not ranked by priority*)

1. Need for education about LiDAR technology
2. Selection of contractors to collect and/or process LiDAR data
3. Lack of standards to guide collection and processing of LiDAR data
4. Inadequate LiDAR data storage, distribution and access
5. Inadequate QA/QC in collection and processing of LiDAR data (e.g. ground truth/control system)
6. Inadequate data transformation/conversion in software
7. Lack of technical capacity/understanding of data processing/accumulation of errors
8. Lack of funding for LiDAR projects
9. Need for federal leadership

To address the challenges listed above, suggested actions, including a lead agency and other key participants, were generated by each group. Once again, similar ideas were discussed in many of the groups. These suggested actions are summarized below (including what role the federal government may or may not have in executing the action).

Challenge	Action(s)	*Federal role*
1. Need for education about LiDAR technology	a. Increase formal, i.e. classroom, education	*Outside federal scope*
	b. Complete costs/benefit study; demo project	*Collaborative*
	c. Plan training/outreach, e.g. webinars	*Clear federal role*
2. Selection of contractors to collect and/or process LiDAR data	a. Encourage or permit Quality Based Selection	*Outside federal scope*
	b. Include QA/QC requirements	*Collaborative*
3. Lack of standards to guide collection and processing of LiDAR data	a. Develop minimum standard	*Expected federal role*
	b. Develop application specific standards	*Federal role for certain applications*
4. Inadequate LiDAR data storage, distribution and access	a. Improve existing systems	*Federal and state roles*
	b. Ensure inclusion of metadata	*Federal and state roles*
8. Lack of funding for LiDAR projects	a. Collaborate among agencies	*Possible federal role*
9. Need for federal leadership	a. Follow single agency	*Strong federal role*
	b. Follow agency committees	*Strong federal role*

Unfortunately, time did not permit the groups to address all nine priority challenges; in fact, no groups brainstormed solutions to challenges five, six, or seven. It is unclear if these challenges were not addressed because of limited time or if the participants could not think of actions to pursue. Interestingly, these challenges were those raised by partners that generated the planning of this workshop. NGS, as part of its mission and strategic goals, is already working to help users tackle some of these issues.

Challenge	NGS ongoing and supporting work
5. Inadequate QA/QC in collection and processing of LiDAR data (e.g. Ground truth/control system)	a. Improvements to datasheets b. Height Mod guidelines support cost-effective way to update benchmarks' elevations c. New geopotential (i.e. vertical) datum will be even more cost-effective means to establish accurate vertical control
6. Inadequate data transformation/conversion in software	a. Transformation tools will be developed for new geopotential datum
7. Lack of technical capacity/understanding of data processing/accumulation of errors	a. Improving documentation of accumulation of errors within direct observation, models, and tools used to establish high accuracy vertical control

Panel discussion summary

After some initial comments from the speakers, the audience asked specific questions that both the panelists and other members of the audience addressed. Information that was shared regarding a few specific topics that may assist a broad audience is summarized below. Notes that captured all the questions and answers are available in Appendix B.

1. How can we improve education about LiDAR technology, acquisition, and data processing?

- The field of photogrammetry, in both academia and industry, provides a good education model that LiDAR can follow, illustrating that there is not a single solution, but many facets of a robust education system. The end goal should be to create a wide range of education resources from university coursework and textbooks to opportunities for hands-on experience.

2. What resources are available for data distribution and storage?

- The Center of LIDAR Information Coordination and Knowledge or CLICK is a website where LiDAR datasets can be made publicly available (http://lidar.cr.usgs.gov/).
- Earthscope (http://www.earthscope.org/), funded by the National Science Foundation, has a super-computer that has potential for innovative solutions for LiDAR data storage and distribution.
- The National Elevation Dataset (NED) is currently served through the USGS Earth Resources Observation and Science (EROS) Center (http://eros.usgs.gov/). Efforts are currently underway to explore LiDAR data gridded to 1/27 arc second.
- NOAA's Coastal Services Center administers Digital Coast (http://www.csc.noaa.gov/digitalcoast/) which directs users to online datasets and hosts NOAA's bathymetric data.

- The National Digital Elevation Program (http://www.ndep.gov/) website coordinates what data is already available, what partners are involved, places of common interest, and where there is a common data need.

3. *What LiDAR standards already exist and are publicly available?*

- USGS National Geospatial Program LiDAR Guidelines and Base Specification, Version 13, ILMF 2010 (http://lidar.cr.usgs.gov/USGS-NGP%20Lidar%20Guidelines%20and%20Base%20Specification%20v13%28ILMF%29.pdf) address how LiDAR data is collected, processed, and includes a level of specificity (e.g. hydroflattening).
- FEMA specifications for QA/QC (http://www.fema.gov/library/viewRecord.do?id=4345)
- ASPRS Standards Committee publishes a variety of guidelines, specifications, and standards (http://www.asprs.org/Standards/)

4. *Are there opportunities to get additional funding for LiDAR projects?*

- Cost-sharing may be possible if LiDAR data collection meets USGS standards or needs.
- Other federal partnerships may be available with agencies like DHS's FEMA and USDA's National Resources Conservation Service (NRCS).

5. For publically available data, what sort of metadata can or should you require to control the quality of the data as well as some level of QA/QC?

- Given the challenges of data storage itself, currently the onus is often on the data provider to provide accurate data that includes QA/QC as well as adequate metadata.
- Interagency Integrated Ocean and Coastal Mapping (IOCM) working group is trying to come together and get a metadata standard that can be applied to data already collected.
- North Carolina has modified its license laws to include photogrammetry, and there is now more ownership and reliability surrounding data in the public domain. However, once data is in the public domain, it is available for anyone to use and can be applied beyond the accuracy of the data.

Conclusions and next steps

NGS was extremely pleased with the level of interest indicated by the high attendance at this workshop. The issues raised by some of NGS' partners prior to this event do indeed seem to be concerns widespread in the LiDAR user community.

The variety of topics presented, and the diversity of the audience, demonstrated the power and value of LiDAR technology. The input provided by the members of the audience during the break-out sessions showed a wide range of experiences using LiDAR, which seems to be typical of the broader user community. Interestingly many aspects of LiDAR data collection, processing, and products were listed by some groups as both the positive and negative experiences, like the fact that it is far more robust than photogrammetry, and that the technology is evolving at such a rapid pace. As education resources continue to increase and industry standards become more universal, it is likely that the negative experiences will diminish.

Vertical control for LiDAR surveys, e.g., one of the concerns that inspired the workshop in the first place, is sorely lacking in the experience of some people, but a matter of course in the experience of others. Sharing the best practices from experienced users will greatly benefit those who currently struggle to

ensure accurate vertical control. It will remain important for NGS, with tremendous expertise in establishing highly accurate positions and elevations, to remain engaged in this effort.

Most in attendance would agree this workshop was successful as far as it went. Speakers mentioned numerous resources that were new to many users, such as web sites for data distribution, and standards that are in place or being developed. These are tools the audience can take and use immediately.

Still, further action is needed, and NGS plans to respond with some actions to begin addressing these challenges. The National Height Modernization Program, representing the geodesy side of attaining accurate elevation data, will:

- Interact and partner more with NGS's remote sensing office.
- Participate in ASPRS conferences and look for other opportunities to reach out and educate the remote sensing community.
- Increase its interaction with USGS to develop outreach and educational material that will bridge the remote sensing and positioning (i.e. surveying and geodesy) user communities.

Other possible future actions include:

- Identifying webinars on a variety of topics, such as outlining best practices of writing contracts.
- Developing lessons learned documentation when proper ground control was or was not established.
- Completing cost/benefit analysis of investing in a new geodetic network rather than having to fix work after data collection.

Meanwhile the users that participated in this workshop can work with the academic community to make sure the training and educational opportunities are created. They can also share information as they gather it, on best practices and lessons learned, on solutions to storage and distribution problems, on QA/QC procedures and other challenges identified.

NGS will plan on revisiting this subject in future years to see if progress has been made. Another workshop can be held, perhaps in partnership with another agency.

Acknowledgements

An event like this does not happen without a lot of effort from key individuals. I would like to close with my thanks to everyone who contributed to making this workshop successful:

To NGS Director, Juliana Blackwell; Geodetic Services Division Chief, Gilbert Mitchell; and NGS leadership, for supporting this workshop and taking the time to participate.

To the Speakers, for the time you took to develop your presentation, and come to Silver Spring, in many cases from great distance, to participate. All presentations were very well received, and contributed to a well-rounded and informative program.

To the Planners, too numerous to name, for your suggestions for topics and speakers. As I struggled to pin down how I wanted to focus the program, your comments and input were invaluable. People from USGS, ASPRS, NOAA, NFS, FEMA, state government and academic partners (NC, IL, TX), and private industry all contributed with suggestions in planning sessions via teleconferences and email. Special thanks to Monica Stich and Christine Gallagher who kept me on track.

To Lucy Hall, Sonita Tiwari, Marcia Butler, who managed the logistics on short notice and in spite of my absence. Everything ran smoothly because of your efforts.

To Erika Wilson and Jason Woolard who published the announcement and presentations on the Corbin Training Center web site, made possible the morning webinar session, and put extra effort into overcoming problems with recording of the webinar.

To the NGS personnel who facilitated table sessions and took notes: Rebecca Waddington, Sonita Tiwari, Lucy Hall, Monica Stich, Christine Gallagher, and Aria Remondi.

To Christine Gallagher and Vicki Veilleux for all your help compiling and publishing this report.

And of course to the NGS Height Modernization Program partners whose interests and concerns sparked the idea for this workshop in the first place.

Thank you all.

Renee Shields, Height Modernization Program Manager
September 15, 2011

Appendix A: Break-out Session Results

Break-out Session: Participants worked in small groups to create a list of most important or most frequently encountered issues in acquiring or using LiDAR data. After reporting problems out to the entire group, time was spent to brainstorm solutions in each small group.

Task 1: List your experiences, positive and negative, with LiDAR. Be as specific as you can. If you have not yet used or needed LiDAR but would like to, list your greatest concerns. When you are done, individually select your top 3 items, then vote for the top 3 as a group.

Group 1

Positive

- Fast, thorough, and detailed
- Improves safety for employees (terrestrial)
- Access
- Can do surveys at night
- Endless applications
- More robust than photogrammetry in some applications
- Rapidly evolving technology

Negative

- *Bad (passive) control, i.e. system is dependent on reliable control which isn't available* ***[#3]***
- Too much information (features + points in cloud)
- Inconsistent coordinate system conversion between different software
- Lack of metadata (datum identification)
- Processing software should be streamlined and connected to the data collectors
- Calibration
- *Accumulation of errors w/ different enabling technologies* ***[#1]***
- *Finding bare earth underneath vegetation in marshes* ***[#2]***
- More robust than photogrammetry in some applications
- Rapidly evolving technology
- Lack of training for interpreters of LiDAR data

Group 2

Positive

- *Potential for automated feature extraction* ***[#1]***
- Tools available are incredible
- Widely available technology
- Mobile LiDAR potential
- More robust elevation data transformation
- Need to tie to historical data to monitor change

Negative (Group 2 continued)

- *Lack of standards (importance of education)* ***[#2]***
- *Use of technology w/o tech. capacity (data quality may or may not meet engineering design needs)* ***[#3]***
- People do not know their data needs
- Need a delete button – never get rid of data
- Lacking standards and specifications of how to determine spatial data accuracy.

Group 3

Positive

- Mobile LiDAR safety aspect
- Need control & maintain control
- Great for filling in the gap to provide elevation changes in a wide area
- Rapid way of obtaining data
- Data can be collected in all weather
- Watershed/stream volumes

Negative

- Airborne limited to terrain +/- 2cm accuracy
- Mobile processing time, data storage
- Time consuming
- Expensive
- *Education and coordination for smaller guys* ***[#1]***
- Design software (CAD software)
- *Lack of standards and guidelines* ***[#2]***
- Does not replace the need for height mod
- *Repository of the data* ***[#3]***

Group 4

Positive

- Laws, photogrammetry
- License professional
- Technology and software improvements
- Control network

Negative

- *Lack of ground truthing* ***[#3, tied]***
- No follow-up, notification
- *Different agencies/groups don't know what to ask* ***[#3, tied]***
- *Contracts not written well* ***[#2]***
    - No standard SOW
    - Difficult to understand specs
- *Education level – software training* ***[#1]***

Group 5

Positive

- Added value
- Wealth of uses
- Applications for many situations (100's)
- Versatile product
- Crown volume for forests
- Post fire – flow and flood modeling
- Can be a cost savings for the data
- Change detection
    - Land use
    - Subsidence
    - Flood plain
- Emerging technology

Negative

- Accuracy 2-6 cm on average based on the geoid which is not reliable
- *Lack of understanding and education **[#1, tie]***
- *Lack of policy and guidelines**[#1, tie]***
- *Importance of geodetic controls and how they relate to LiDAR **[#1, tie]***
- *Sources of funding and cost **[#3]***
- Data storage (cost)
- *No clear leader at the federal level **[#2]***
- Emerging technologies

Group 6

Positive

- Coordinating Lidar council
- Merge LiDAR model with conventional methods to get the work done quickly
- Flexibility in Lidar types – saves $$
- Easy to share data
- Dr. Maune's briefing – Endless applications

Negative

- Lack of National Standards - USGS has standards but they are not used by private industries
- *More education for users – cost, accuracy, etc. **[#1]***
- Variations in determining aircraft position
- *Need qualification standards for hiring contractors **[#3]***
    - Acceptance criteria
    - Need to know what ?s to ask
- *Need resource list of experts **[#2]***
- Private interests do not tie into NSRS
- Data needs to be in usable format to share
- Two data sets both met criteria but had 2' difference at boundary

Task 2: Given the top issues identified in Task 1, brainstorm ideas for actions that can be taken to address these issues. Include who should take the lead for that action, and what other people/ organizations/entities should participate.

Top challenges facing users of LiDAR data (*list not ranked by priority*)

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7. Lack of technical capacity/understanding of data processing/accumulation of errors
8. Lack of funding for LiDAR projects
9. Need for federal leadership

Group 1

Issue	***Action***	***Lead***	***Participants***
Education	University Courses and workshops (geography, civil engineering, surveying)	Universities	
Education	Availability to other agencies as contracts	State/federal	private
Selection of contractors	Include QA/QC requirements in contracts	Funding agency	contractors
Selection of contractors	education		
Lack of standards	Standards should be customized to specific activity/contract	Funding agency/ QA/QC people	contractors
Lack of standards	Minimum standard should be maintained to enable data sharing	Federal (USGS + NGS + FGDC)	
Data storage, distribution and access	Freely available data when public is funding (and metadata)	States/federal	Everyone has access
Funding	Interagency collaboration	Consortium (collects funding from different agencies and allocates)	Federal/state/private
Federal leader	USGS is leader	USGS	

Group 2

Issue	*Action*	*Lead*	*Participants*
Education	Quality education – more math & Science K-12	State and local	Schools, teachers, students
Education	Webinar/seminar, < one week class		USGS, NOAA
Education	Quality education; BS degree	ABET	colleges
Selection of contractors	Go QBS rather than low bid	State	
Lack of standards	Development of Standards and guidelines	FGCS and other agencies	USGS, NOAA, all in NDEP
Federal leader	Development of Standards and guidelines	FGCS and other agencies	USGS, NOAA, all in NDEP

Group 3

Issue	*Action*	*Lead*	*Participants*
Education	Education/Coordination/Administration of partners and users	Universities	
Education	Cost benefits study: who, what, why	???	Federal, state, local gov, private
Education	Converting technical to non-technical terms		Industry & Prof. organizations
Education	Demo project	ASPRS	Any agency willing to step up and foot the bill
Lack of standards	Lack of Standards – compliance with limited funding		
Data storage, distribution and access	Data storage, distribution, access – raw data and everything else	State agency as clearing house	Anybody and everybody

Group 4

Issue	*Action*	*Lead*	*Participants*
Education	Education @ university level – background/theory	Federal (money)	State licensing boards
Education	Outreach (all levels) - Advanced QA/QC workshop/training - What LiDAR can do for you - Datums	States	Height mod partners, professional associations
Selection of contractors	Promotion of QBS (Quality Based Selection)	Federal/state	Industry & Prof. organizations
Lack of standards	Education on applications, etc./	Professional associations	all
Data storage, distribution and access	Storage of raw data and data deliverables	Federal where money	

Group 5

Issue	*Action*	*Lead*	*Participants*
Education	Education	Industry	Customers, stakeholders
Lack of standards	Lack of standards - Data storage - QA/QC - Data transformation - Data processing	Government	Customers, stakeholders ASPRS, FGDC Industry Professional associations

Group 6

Issue	*Action*	*Lead*	*Participants*
Education	Webinars, Online Modules – make high priority, pay to do it	Partnership – ASPRS/ NSPS/NGS/USGS	Everyone
Education	Curriculum-University level	Done	
Selection of contractors	Quality based – Brooks Act	Federal	Industry
Selection of contractors	Selection Criteria to evaluate proposals	State	
Selection of contractors	Reference List	USGS, NOAA, experienced agencies	
Selection of contractors	Guideline for contract writing - template	Depends on needs	
Lack of standards	Adopt USGS Standards as starting point with clear exceptions – less likely to receive joint funding	USGS, FGDC, NGS-geodetic control	
Data storage, distribution and access	State websites	State	
Data storage, distribution and access	CLICK website	Federal	
Data storage, distribution and access	Open Topography Portal (O.T.P.)	NSF	
Data storage, distribution and access	NOAA's Digital Coast	NOAA	

Appendix B: Panel Discussion Notes

All speakers from morning presentations were invited to participate. Chris Parrish, Dave Doyle, David Maune, Greg Snyder, and Gary Thompson all formally participated in the panel in the front of the meeting room.

To begin, Renee invited speakers to comment on or continue any of the challenges that were discussed during the break-out sessions. After some initial comments from the speakers, the audience asked specific questions that both the panelists and other members of the audience addressed.

Chris Parrish (NOAA) – To continue on the topic of LiDAR education, we can and should look to the analogous field of photogrammetry. It is the most mature remote sensing field, and after decades of development, there are now robust education resources ranging from university coursework and textbooks to opportunities for hands-on experience. Photogrammetry provides a good education model that LiDAR should follow, illustrating that there is not a single solution, but many facets of a robust education system.

David Maune (Dewberry) – To continue on the topic of data distribution and storage, I want to mention existing publicly available resources.

- The Center of LIDAR Information Coordination and Knowledge or CLICK is a place that LiDAR datasets can be made publicly available (http://lidar.cr.usgs.gov/). It is an open portal to share topographic information.
- Earthscope (http://www.earthscope.org/), funded by the National Science Foundation, has a super-computer that has potential for innovative solutions for LiDAR data storage and distribution.
- The National Elevation Dataset (NED) is currently served through the USGS Earth Resources Observation and Science (EROS) Center (http://eros.usgs.gov/) which has its strengths and weaknesses in delivering large datasets. Efforts are currently underway to explore LiDAR data gridded to 1/27 arc second.
- NOAA's Coastal Services Center administers Digital Coast (http://www.csc.noaa.gov/digitalcoast/) which directs users to online datasets and hosts NOAA's bathymetric data.
- The National Digital Elevation Program (http://www.ndep.gov/) website coordinates what data is already available, what partners are involved, places of common interest, and where there is a common data need.

– To continue on the topic of LiDAR standards, USGS National Geospatial Program LiDAR Guidelines and Base Specification, Version 13, ILMF 2010 (http://lidar.cr.usgs.gov/USGS-NGP%20Lidar%20Guidelines%20and%20Base%20Specification%20v13%28ILMF%29.pdf), are a good place to start. The guidelines address how LiDAR data is collected, processed, and includes a level of specificity (e.g. hydroflattening). Additionally, there may the opportunity for cost-sharing if your LiDAR data collection project meets USGS standards or needs; the cost-sharing may make it worthwhile to follow USGS standards even if they exceed your own data needs.

Nina Garfield (NOAA) – Do the national standards apply to data acquisition or data processing?

David Maune (Dewberry) – The standards are more concerned with the quality of end products or deliverables; for example, identifying specific point density or accuracy requirements.

Sheena Beaverson (Illinois) – We understand that the USGS LiDAR standard is a cartographic standard, and thus it may have limitations for the non-cartographic LiDAR applications. Regarding EROS and CLICK, why is a full point cloud not always available? Who will start addressing issues about the quality of data available through these sites and/or clearinghouses and what is the timeframe?

David Maune (Dewberry) – Although USGS is making these datasets available, data storage remains an issue. USGS is exploring possible solutions including its interest in the potential of using a super computer.

Greg Snyder (USGS) – CLICK site is more than just data; it is intended to function as a library. USGS is currently inundated with data and trying to work off the back-log. The current data management policy is to index the data and serve it in the form that it is received. If the data is received as a point cloud, the full point cloud should be made available. However, data served through the National Elevation Dataset (NED) may have been downscaled to fit the NED grids. USGS is also locating other partnerships when possible with agencies like DHS's FEMA and USDA's NRCS.

Renee Shields (NOAA) – The proliferation of different terminology and datasets in our discussion so far illustrates that one challenge is fluency in LiDAR terminology itself.

Cliff Mugnier (Louisiana) – LiDAR coverage of Louisiana is nearly 100% because it has been collected by FEMA in support of their Digital Flood Insurance Rate Maps (DFIRMs). Roy Dokka had been researching the QA/QC that was in done in the collection of this data. He found that checks were often clustered and that many parishes had far less checks than were required for specific land features, types of land cover, etc. He found there to be significant elevation errors on the order of feet. Other issues arise when contractors unfamiliar with the area tie their data collection to benchmarks known locally to be in error. For your publically available data, what sort of metadata can you require to control the quality of the data as well as some level of QA/QC?

Dave Doyle (NOAA) – NGS has a good model that can be adopted to serve publically available data. To be made available through NGS, data submitters must follow NGS standards. This ensures a standard quality if met before it is put out there publically.

Chris Parrish (NOAA) – While data quality is important, we cannot forget the tremendous challenge that data storage presents. As a result, we should commend that great service that USGS and CSC provide by taking on the challenge of storing this tremendous volume of data. The effort required to take in and share publically this amount of data may mean that they are limited to simply serving out what they receive from data submitters. To expect independent QA/QC and metadata responsibilities from them is a great deal to ask. The onus should really be on the data provider to provide accurate data that includes QA/QC as well as adequate metadata.

David Maune (Dewberry) – Addressing the issues of using benchmarks without accurate or updated elevations, I would like to share an anecdote from a project that was completed along the Florida panhandle. Before the project began, Ronnie Taylor advised those involved to complete their own geodetic network because the quality of the existing benchmark network was suspect. The advice was followed, and they paid $900K to get a geodetic network that they could trust. The geodetic fieldwork found differences of as much as 2 ft from published benchmark elevations.

Amar Nayegandhi (Jacobs Technology) – Interagency Integrated Ocean and Coastal Mapping (IOCM) working group is trying to come together and get a metadata standard that can be applied to data already collected. Additionally, data storage of metadata has to be assigned. To try and simplify the process, the first step being pursued is finding a way to store the metadata. Then, the process can be applied to the distribution of larger data sets.

Renee Shields (NOAA) – The Height Modernization (Height Mod) Program is very interested in the metadata for LiDAR data. Additionally Height Mod is interested in the geodetic control LiDAR data is tied to, relating accuracy of LiDAR data to the accuracy of the geodetic control, and the shelf-life of the LiDAR data.

Stacy Lyle (Texas) – I believe that LiDAR has to be collected by a professional and used by a professional. Can we exert any control over someone using the data that is in public domain?

Gary Thompson (North Carolina) – North Carolina has modified its license laws to include photogrammetry. It is important and has been successful in NC. There is now more ownership and reliability. Still, once data is in the public domain, it is available for anyone to use. Unfortunately, we have heard of professionals that use the data beyond the accuracy of the data. To combat this problem, we promote education in the private sector and at universities to inform folks of limitations of the data and warn them of the problems in exceeding those limitations.

Brad Rister (Kentucky) – Are there FCC restrictions of LiDAR data collections or restrictions from other federal agencies that we need to be aware of? Also, is anyone aware of the use of LiDAR within the transportation research field specifically looking at bridge deflections or dynamic movement?

Chris Parrish (NOAA) – Addressing your question about bridge deflections, yes I am aware of studies where bridges were monitored for a set period of time using LiDAR technology. However, I am unsure if this has been done continuously, in real-time. Terrestrial LiDAR does have the advantage of higher density than most airborne LiDAR. Still, the ability of measure deflections would be dependent on the magnitude of the deflection compared to the accuracy of the LiDAR data.

Addressing your question about restrictions from federal agencies: the only restrictions I am aware of are eye safety issues with the transmit pulse. There is concern that there may be greater restrictions and scrutiny in the future. However, the probability is really low that you could harm someone. The only other challenge is navigating restricted airspace which has to be coordinated with FAA.

David Maune (Dewberry) – Adding to the comments on restrictions related to eye safety, LiDAR manufacturers go through stringent processes to protect for eye safety.

Amar Nayegandhi (Jacobs Technology) – I concur that there are very strict guidelines on eye safety, and manufacturers must follow them strictly. Questions have been raised about possible danger to birds or fish, but there are no restrictions in this regard at this time.

Peter Jenkins (Minnesota) – I can speak to the question about LiDAR technology being applied to bridge monitoring. For the most part, other technologies are used. However, LiDAR can be used like a sensor. I can speak to an example where another type of laser was used, and perhaps LiDAR could be applied similarly. Minnesota DOT used an Electromagnetic Distance Measurement (EDM) shooting at glass to monitor a ballast for a temporary train route to make sure the tracks remained level during a construction project. A cell phone was called if a tolerance was reached.

Renee Shields (NOAA) – To wrap up, thanks to everyone for attending, and participating by providing your input in the group sessions. The notes and a report will be published online, along with the power point files. The presentations this morning were recorded, but we did have some problems syncing them with the power points. Once this has been resolved they will also be provided. Feedback forms have been distributed, so please take the time to complete them. To our Height Mod partners, we have a meeting tomorrow in the next building. Lastly thanks to all those who made the workshop possible, including the speakers, and my colleagues at NGS who did all the hard work to bring this together.

Juliana Blackwell (NOAA) – I also want to thank you for coming, and I hope it was beneficial. I thank Renee for putting this workshop together; I personally learned a lot today.

Appendix C: Input collected before Workshop

Registrants were invited to answer the following questions to assist the speakers in knowing the background and interest of the audience. Recurring responses are summarized below. All responses (11 to 17 per question) are listed in their entirety beginning on the second page of this Appendix.

1. What application(s) do you or does your agency use LiDAR data for?
-transportation/infrastructure design and planning
-hydraulic and hydrologic models
-floodplain and flood hazard mapping

2. What major problem(s) have you or has your agency encountered when acquiring and/or using LiDAR data?
-vertical accuracy, absolute accuracy (relating to ground truth), accuracy with vegetated cover
-large data sets challenging (e.g. point clouds)
-cost barriers
-QA/QC, contracting specs, metadata

3. What is the desired LiDAR vertical accuracy for your application?
-varies greatly/by application but two main groups are: (1) sub cm, 1 cm, 2 cm and (2) 0.1 ft, 0.3 ft, 0.5 ft

4. With regard to LiDAR, how frequently does the elevation data need to be updated to satisfy your requirements?
-most responses were 3-5 or 5-10 years
-one required 6 months
-one mentioned post-event such as a hurricane

5. What elevation products (e.g. contours, break lines, DEMS) do you or does your agency use?
-many responses listed contours, break lines, DEMS, DTMS, and point clouds

6. Additional comments or topics that should be addressed during the workshop can be listed below:
-cost
-vertical control not linked to bench marks
-national standards
-QA/QC
-confidence in LiDAR and INSAR has to continue to grow

7. Are you participating in the workshop as a Classroom or Webinar attendee?
Webinar: 5; Classroom: 11

8. What region of the country are you from?
West= 5; Central=1; Great Lakes=3; Gulf=2; Southeast=3; Northeast=1; DC=1

All responses (11 to 17 per question) are listed in their entirety below.

1. What application(s) do you or does your agency use LiDAR data for?

- We have used Lidar based DEMs in comparisons to earlier topographical maps to estimate land-surface subsidence across large areas where we do not have traditional benchmarks or GPS sites.
- Supplement imagery for geometric adjustment process. Densify imagery or density Lidar with Imagery
- We use mobile LiDAR for scanning highways and bridges. These scans are used to develop base maps in CADD for highway projects.
- Hydraulic modeling and pre-engineering design with the airborne data. Limited final design with the terrestrial data
- We supply a state agency with geodetic control and ground truth 3D coordinates for LIDAR map accuracy checking.
- None
- Transportation maintenance, investigation, and preliminary design.
- Engineer, roads, and pre-site development. Forest analysis: Tree structure, basal area (tree), % tree cover, micro hydrology.
- power line, topographic mapping,
- Examples include flood hazard studies; image draping, image rectification; subsidence studies; site suitability studies.
- hydrologic modeling
- Would like to use to obtain engineering survey data.
- topographic, civil infrastructure, cultural heritage
- Elevation analyses - slope, aspect, etc.
- Geologic mapping (ISGS), highway planning and engineering (IDOT), FEMA flood map revisions (ISWS).

2. What major problem(s) have you or has your agency encountered when acquiring and/or using LiDAR data?

- Accuracy and Reliability of Lidar in heavily vegetated areas, along with processing differences between previous and more current Lidar efforts. Also housing growth creates man-made differences in elevations that are not related to subsidence issues. Telling the two apart is difficult.
- Required absolute accuracy not possible without very costly survey control e.g. requires 2 surveys… diff leveling for Z and GPS rapid static for XY Obtaining mapping with accurate vertical data.
- The cost of getting into the acquisition business. Some training time for certain software use and the storage issues.
- If differences occur between LIDAR data and ground truth data, how can the LIDAR be adjusted to fit ground truth data? We do not believe LIADR data can be adjusted to post mission ground truth control as each LIDAR data point is an independent measurement.
- NA
- On the acquisition side of things - we cannot justify the funds required to do large-scale projects since we use a fraction of the data. Federal funding through USGS is set up to where projects are approved within a fiscal year. This does not allow for any planning more than 6-8 months or less.

Other federal funding seems to drop in on short notice as well. There needs to be a better budgeting process for partnerships at the state and local level. Problems encountered with LIDAR use - the biggest problem seems to be making use of large data sets. CAD and GIS applications do not handle the point cloud data and products very well. We are investigating other applications that allow us to work with these large scale data sets. Would like to hear about success/failure stories about available software applications.

- Lack of consist contracting specifications to aid the end user and the contractor. Cost Delivery schedule.
- low vegetation classification
- Data accuracy is the single most problematic issue facing LiDAR acquisition and utilization in Louisiana. Many LiDAR acquisition flights have used NGS benchmarks for vertical control. This is a problem in LA because far too benchmarks are invalid. Vertical control based on CORS stations is slowly being adopted, but we've encountered issues related to the inability of sensor technology properly accommodating very flat (monotonous) surfaces.
- Size of data sets and getting into design packages, MicroStation and Geopak.
- large data size, lack of adoption of a standardized format (E57) by software developers.
- Agencies who contracted to acquire data for individual counties did not perform a thorough QA/QC assessment upon data delivery. By the time our agency received the data for long-term stewardship, contract period has closed and blatant errors in the data cannot be rectified. Also, agencies contracted to acquire and process data are lax in providing sufficient metadata.

3. What is the desired LiDAR vertical accuracy for your application?

- Our subsidence monitoring network (over 80 GPS points) is considered to be +/- 1 cm. So we would like to see Lidar at least that accurate, if not more accurate.
- 2 cm or less
- We need sub-centimeter for our vertical control.
- The accuracy results are plenty good but definition at design critical points is lacking without high point density.
- 10-15 cm as quoted by the LIDAR vendors.
- NA
- USGS Specifications: Vertical accuracy requirements using the NDEP/ASPRS methodology are: FVA <= 24.5cm ACCz, 95% (12.5cm RMSEz) CVA <= 36.3cm, 95th Percentile SVA <= 36.3cm, 95th Percentile
- Varies 10-100 cm horizontal 10-25 cm vertical
- 0.1'-0.5'
- <1m
- .5 foot
- <0.1' urban projects <0.3' rural projects
- better than 1cm.
- It varies. We have a wide user-base working in compliance with different federal agencies (FEMA, USACE, USGS, USFS, USDA).

4. With regard to LiDAR, how frequently does the elevation data need to be updated to satisfy your requirements?

- Lidar was flown in 2008 and in 2001. A 5 to 10 year cycle is probably about the best we can hope for.
- Always

- Depending upon the project we have been establishing a control point every 300-600 feet depending upon desired mapping.
- For pre-design and hydraulic modeling it would be a number of years and this would be site specific. For final design it would be acquired for every project.
- Some applications are repeated annually, e.g. for coastal erosion monitoring. Also after severe weather events (hurricanes flooding, etc.).
- NA
- Depends on the amount of development in a county: - rural = 8-10 yr - urban = 4-6 yr
- Not very frequently for most applications. In some cases, a pre and post LiDAR collection may be desired for some engineering applications.
- ?
- Inconsistent subsidence rates across the gulf coast, along with a receding shoreline nictitates a 2-5 year revisit.
- Only if conditions change substantially before the project is constructed.
- every 6 months.
- 5+years
- Currently, LiDAR data is available for 1/5th of Illinois. We anticipate 100% coverage within 3 years. It is difficult to set an update rate before we reach 1st time coverage.

5. What elevation products (e.g. contours, break lines, DEMS) do you or does your agency use?

- Essentially bare earth DEMs, so that we can compare to historical DEMs. The USGS mapped 1ft contours from the 1915 time period and created a DEM that we compared the 2001 Lidar DEM from FEMAs TSARP project.
- Point clouds
- We use contours, breaklines, dtms.
- DEM's for pre-design and hydraulic modeling and DTM's for final design.
- We are looking for 2 foot contours.
- DEMS DTMS Contour lines break lines shaded relief spot elevations subsidence maps (INSAR)
- Point Cloud, DEM, and TIN are minimum requirements. Contours and breaklines are nice to have if funding is available.
- All: Contours for mapping products. Break lines for hydrology DEMs for GIS and a multitude of applications.
- we are a provider, not user
- Contours, Breaklines, DEMS, TINs, etc.
- all of the above
- DTM,s consisting of ,ass points, break lines, contours, boundaries, voids, islands. DTM's are used to determine volumes based on DTM generated cross sections or surface differences.
- contours, breaklines, DEMS, grids in GIS.
- National Elevation Dataset
- LiDAR classified point cloud, DEM, contours, breaklines.

6. Additional comments or topics that should be addressed during the workshop can be listed below:

- We have tinkered with INSAR and Lidar but do not have an overwhelming confidence yet in either. We see great potential and are willing to continue researching both avenues.
- Heights vs elevation accuracy of geoid for sub 2 cm vertical requirements. Field to office to field transformation e.g. Lidar and height mod concerns/issue for data acquisition to design machine

control The state of mobile lidar especially the post processing and feature extraction software status.
- Can a national standard for LIDAR mapping be created to ensure a consistent accuracy standard?
- Cost Need for Geodetic Control for Lidar data
- Would like to know what FEMA plans are for LIDAR acquisition Is this effort being coordinated with the USGS LIDAR effort?
- Cost: current and future projections State of the art
- How can height Modernization Partners contract with and assist the NGS in GRAVD?
- Vertical control that isn't dependent on benchmarks is the most critical.
- I'm a newbie to LIDAR, and am interested in its application in the area of cultural resource protection (Native American mounds, stone structures).
- There is a distinct need for sharing of deliverable QA/QC workflow protocols and hands-on, formal classroom training on data QA/QC as well. Informal webinars don't cut it.

7. Are you participating in the workshop as a Classroom or Webinar attendee?

- Classroom: 11
- Webinar: 5

8. What region of the country are you from?

West= 5
Central=1
Great Lakes=3
Gulf=2
Southeast=3
Northeast=1
DC=1

Appendix D: Feedback collected after Workshop

Participants who attended the workshop in person had the opportunity to give feedback to regarding the 1-day event. The questions that were answered and the averaged results are listed below.

1. **How beneficial was the information presented at the workshop?**
   - o Extremely beneficial (4)
   - o Very beneficial (3)
   - o Moderately beneficial (2)
   - o Slightly beneficial (1)
   - o Not at all beneficial (0)

   AVERAGE RESPONSE: Very beneficial (3.1)

2. **Was there too much technical information, too little, or about the right amount of information covered?**
   - o Much too much (6)
   - o Somewhat woo much (5)
   - o Slightly too much (4)
   - o About the right amount (3)
   - o Slightly too little (2)
   - o Somewhat too little (1)
   - o Much too little (0)

   AVERAGE RESPONSE: About the right amount (2.9)

3. **How organized was the information presented at the event?**
   - o Extremely organized (4)
   - o Very organized (3)
   - o Moderately organized (2)
   - o Slightly organized (1)
   - o Not at all organized (0)

   AVERAGE RESPONSE: Very organized (3.1)

4. **How clear were the objectives of the event?**
   - o Extremely clear (4)
   - o Very clear (3)
   - o Moderately clear (2)
   - o Slightly clear (1)
   - o Not at all clear (0)

   AVERAGE RESPONSE: Very clear (2.8)

5. **How organized was the event?**
   - o Extremely organized (4)
   - o Very organized (3)
   - o Moderately organized (2)
   - o Slightly organized (1)
   - o Not at all organized (0)

   AVERAGE RESPONSE: Very organized (3.2)

6. **Overall, were you satisfied with the workshop, neither satisfied nor dissatisfied with it, or dissatisfied with it?**
   - o Extremely satisfied (6)
   - o Moderately satisfied (5)
   - o Slightly satisfied (4)
   - o Neither satisfied nor dissatisfied (3)
   - o Slightly dissatisfied (2)
   - o Moderately dissatisfied (1)
   - o Extremely dissatisfied (0)

   AVERAGE RESPONSE: Moderately satisfied (5.3)

7. **Do you have any other questions, comments, or suggestions?**

- Extremely broad subject but much data was provided.
- Great job.
- It's a difficult task. I think you need to involve some additional groups. For instance, Earthscope was mentioned. Why not contact them?
- Need to summarize for attendees. Identify purpose(s) of meeting. Identify possible next steps. Follow-up communication needed
- Needed agenda information earlier.
- NGS should develop guidelines for integrating LiDAR air/ground to NSRS
- NGS should strengthen the USGS Draft Standard 13 with guidelines for GNSS procedures to provide aircraft position control.
- Provide ongoing status for the TOP 9 issues as it becomes available. Make place on Wiki for group updating?
- Thank you for holding this workshop. I enjoyed it.
- The information was well organized and the speakers' knowledge helped me further understand LiDAR.
- This was a great workshop! I learned a lot. It was able to speak to multiple levels of familiarity. Thank you for putting this on. I hope the talks will be available for webinar for those unable to attend.
- This was very professional and educational. The NGS is doing a great job of protecting the public and utilizing their budget to attack important issues effecting the overall public. A technical paper/report from this meeting is needed.
- Thought it was great, especially since it was put together on such short notice. Great job!!
- We need an abbreviated version (a road version) of this workshop to take to the local counties to demonstrate the need for a cooperative regional LiDAR project.
- Will there actually be any change? Unless some change on external (outside of participants) education exists, then the event wasn't important. A list of participants would be useful.