Workshop Report

This is the preliminary final report for the workshop. Community feedback on this document and the workshop in general for reporting purposes is welcome. The final version will be submitted to the National Science Foundation before the end of January 2012.
Workshop Report:
“Charting the Future of Terrestrial Laser Scanning (TLS) in the Earth Sciences and Related Fields”

We present here a summary of the workshop entitled “Community Workshop: Charting the Future of Terrestrial Laser Scanning (TLS) in the Earth Sciences and Related Fields” held in Boulder, Colorado on October 17-19, 2011. There were 80 participants at this workshop representing a wide variety of research fields and subdisciplines within the Earth sciences. This workshop was funded by the National Science Foundation Earth Sciences Instrumentation and Facilities program (EAR-1138279).

Motivation

The geosciences are moving into a realm of investigation that requires accurate representation of the earth surface using fully 3-dimensional data capture, display, and analysis on the scale of a centimeter or less. Such accurate and dense data will allow geoscientists to address increasingly complex problems such as time-dependent surface change via erosion, quantifying fault motions via matching feature morphology, and determining local biomass with great precision. This fine scale of terrestrial geodetic data must consist of a holistic mixture of Terrestrial and Airborne Laser Scanning (TLS and ALS), photogrammetry, ground-based Radar, and GPS. Recognition of the pressing need for 3D data collection lead several researchers and the UNAVCO facility to establish the INTERdisciplinary alliance for digital Field data ACquisition and Exploration (INTERFACE) effort to facilitate the TLS and GPS aspects of data collection. This has resulted in the UNAVCO facility adding many Laser Scanners and associated equipment to its GPS holdings, developing critical expertise, and placing an emphasis on the collection of TLS data. The rapid rise in TLS equipment and users has caused the community to develop and diversify rapidly. These has created a critical need for moving to a community agreed structure for describing TLS data and metadata, determining best or better practices, and evaluating the scope needed for TLS support.

This is a rapidly expanding area of interest; getting the community involved at this as yet early stage is critical to the efficient and smooth development of all aspects of the TLS method. For that reason, the organizers assembled about 80 participants for a workshop to start building a TLS community of practice. The results described below are the outgrowth of convergence of participant ideas and experiences, a large demand for TLS data and equipment, and clear consensus on issues repeatedly reached during this workshop.

Introduction

Terrestrial Laser Scanning (TLS), based on Light Detection and Ranging (LiDAR) technology, is part of a suite of new geodetic and imaging technologies that are becoming increasingly important to the Earth sciences community for use in myriad
research applications. TLS, also known as ground based LiDAR or tripod LiDAR, offers an unprecedented capability to image at centimeter-level resolution. 2.5-dimensional surfaces such as topography and fully 3-dimensional shapes such as cultural objects or rock or ice outcrops with overhanging features. TLS instruments are very precise, reasonably portable, relatively easy to operate, and have been used successfully to support a wide range of geoscience investigations including detailed mapping of fault scarps, geologic outcrops, fault-surface roughness, frost polygons, lava lakes, dikes, fissures, glaciers, columnar joints and hillside drainages. Moreover, repeat TLS surveys allow the imaging and measurement of surface changes through time, due, for example, to surface processes, volcanic deformation, ice flow, beach morphology transitions, and post-seismic slip. TLS is applicable to problems with areal extents at the 10-meter to kilometer level where detailed analysis is needed. Concurrent GPS measurements can provide accurate global georeferencing of the TLS data and absolute 3D coordinates, particularly important in repeat studies where the stability of all surfaces is uncertain. Coincident high-resolution digital photography allows the generation of photorealistic 3D images that open the potential to analyze and extract geospatially referenced observations in the laboratory. TLS measurements complement spaceborne and terrestrial radar, airborne LiDAR, and spaceborne LiDAR techniques in providing smaller-scale, higher-resolution plots of important areas and by filling in areas inaccessible by these other techniques.

Over the past few years, there has been significant progress in making TLS instrumentation more available to the Earth science community and in developing best practices for acquiring datasets optimized for scientific investigations. This is can be largely attributed to: 1) improved instrument performance (especially scanning speed and range) combined with sustained or lowered instrument costs; and 2) expanded development of and access to community resources such as the UNAVCO TLS instrument pool. This has led to a dramatic increase in the number of research and education projects that benefitted from TLS technology. However, other aspects of TLS have not advanced at the same rate and are becoming increasingly significant barriers to realizing the full potential of TLS as a tool for the Earth sciences. These limiting conditions to growth include data analysis workflows and tools, data format standards, and metadata standards. Current TLS users typically have developed specialized and often unique workflows optimized for the particular instruments they use and the science they engage in. While effective within its context, this arrangement has led to a heterogeneous approach to TLS data analysis that is not overly conducive to advancing the community as a whole. While there will never likely be a single “silver bullet” approach to TLS data analysis, it remains a tenable goal for the community to identify and develop fundamental guidelines to facilitate the analysis and exchange of TLS based scientific data and findings.

**Workshop Goals**

The essence of this workshop was to bring together TLS users from the Earth sciences and related fields to outline a strategic vision for the future of TLS as applied to a broad
range of research activities. The workshop sought to address the current and future needs of researchers based on the present state of the art and will provide recommendations for the advancement of TLS data acquisition, processing, analysis, and distribution to all levels of the community. The goals of the workshop were to capture ideas, to advance community interest, and to establish requirements needed to pursue current and future trends in: 1) science applications, 2) data processing and analysis, 3) definition and adaptation of formats and standards for data and metadata including data/metadata exchange, archiving, interoperability, precision and accuracy, 4) best structures and practices for community-oriented facilities for TLS hardware, software, and data distribution, and 5) integrated community planning to support future developments and community requirements. Workshop deliverables include reports and web resources encapsulating strategic, community vetted recommendations. These deliverables are relevant to TLS users at all levels, from individual investigators to large scale initiatives such as Critical Zone Observatories, and are particularly useful as strategic aids to help NSF supported facilities such as UNAVCO, INTERFACE, NCALM, and Open Topography best meet the needs of the research community now and in the future.

Workshop Organization

The workshop took place October 17-19, 2011 in Boulder, Colorado at the Millennium Harvest Hotel. Workshop logistics were handled by UNAVCO.

The workshop was proposed and organized by the following individuals:

- David Phillips, UNAVCO
- John Oldow, University of Texas at Dallas
- Doug Walker, University of Kansas
- Ramon Arrowsmith, Arizona State University
- Charles Meertens, UNAVCO

To better represent the broader target audience for the workshop and to enrich and diversify the workshop’s planning, content and products, the following individuals provided invaluable assistance in helping organize the thematic sessions of the workshop, serving as session co-chairs and discussion leaders:

- Benjamin Brooks (University of Hawaii)
- Christopher Crosby (UC San Diego, Open Topography)
- David Finnegan (CRREL)
- Craig Glennie (University of Houston, NCALM)

Important contributions to this workshop were also provided by participants from the U.S. Geological Survey. Jaston Stoker provided one the key presentations during the data sessions. James Howle gave a presentation during one of the evening breakouts. And the dinner keynote presentation was delivered by Gerald Bawden.
The workshop was organized into five thematic sessions consisting of presentations, breakout sessions and group discussions. A summary of these sessions, their content and context is as follows.

**Session 1: Science Applications. Led by David Phillips.** This session was devoted to examples of TLS addressing important research topics. This emphasized the fact that TLS has become an increasingly common technology applied to Earth science research as indicated by the growth of TLS related conference presentations and publications. Compelling support for the proliferation of TLS technology into the science community is found in the several national meetings where TLS applications are fully integrated into science theme session (see 2010 GSA National Meeting and 2010 Fall AGU Meeting). Presenters in this session gave several examples of the use of TLS in a broad number of fields and demonstrated its general utility across research topics in ecology, paleoseismology, glacial processes, volcanic processes, civil engineering and natural hazards. There were no breakout sessions.

**Session 2: Data Processing and Analysis. Led by John Oldow, Craig Glennie and Ben Brooks.** This session and following breakouts was aimed at better understanding the impediments to processing and analyzing TLS data. As such, several issues of registration and integration were raised. Breakouts were motivated by presentations on TLS error analysis, time series analysis as applied to landslides, fault rupture mapping and mobile laser scanning, followed by breakout discussions. Common themes from the breakout sessions were numerous. Participants cited the need for a well-established control/reference frame for the data (although for some data sets this may not be required). This is best defined usually by GPS. There was also discussion on data products and what levels should be supported and required. Lastly, establishing the best practices in data collection and processing to a standard product was considered vital to the future of TLS.

**Session 3: Data and Metadata Formats and Standards. Led by Ramon Arrowsmith and David Finnegan.** The problem of data standards as well as needed metadata is critical to making further progress in the TLS community. These aspects were explored by presenters as well as the subsequent breakout groups. Given that there are and will be several TLS manufacturers who equipment is commonly used, exchange and documentation of the data and collection process is critical. It was observed that GPS data can be freely shared among the research community thanks to the Receiver INdependent EXchange format (RINEX). Unfortunately there is no equivalent open, standard format for TLS data. Manufacturer and instrument specific software is required to view, edit and export data into any common exchange format, such as text or LAS (the airborne LiDAR data exchange format), a process that inevitably involves permanently lost information as well as unwieldy data products that are unlikely to withstand the test of time and software revisions. In addition, the group discussed time for reporting and making data freely available. Discussion ranged from the data needing to be immediately available to allowing investigators to quarantine it for up to 2 years.
Session 4: Community-oriented facilities for TLS hardware, software, and data distribution. Led by David Phillips, Craig Glennie and Chris Crosby. There are several groups currently working on and supporting various aspects of TLS, and this session included presentation on community resources available from UNAVCO, INTERFACE, NCALM, Open Topography and CRREL (Cold Regions Research and Engineering Laboratory). It was clear that each of these groups can and should play an important role in developing the TLS community.

Session 5: Comprehensive Outlook and Plan for the Future. Led by Doug Walker, John Oldow, Ramon Arrowsmith and David Phillips. The last morning was spent with the workshop organizers running breakout sessions to make final recommendations on TLS products, metadata, training and support. The great convergence of ideas lead to group consensus on many issues. Recommendations are given in a later section.

The workshop final program is provided in Appendix A.

The workshop presentations are posted on the UNAVCO workshop web page: http://www.unavco.org/community/meetings-events/2011/tls/presentations/presentations.html

Workshop Participants

The total number workshop registrants (90) and onsite participants (80) was nearly double the number anticipated in the initial workshop proposal (50). We interpret this as being a strong indication of community interest in TLS and, based on the workshop's outcome, also a strong indication of the community's interest in and evolution toward greater organization and sophistication. The list of participants is provided in Appendix B.

Relevant statistics regarding workshop participation:

- Participants anticipated in proposal: 50
- Total workshop registrants: 90
- Total onsite workshop attendees: 80
- Total student attendees: 21

It is notable that 21 of workshop participants (26%) were students. Moreover, most of these students are actively using TLS in their current research. Several of the invited presentations were given by students as were many of the poster presentations.
Figure 1. Photograph of workshop participants.

Figure 2. Lidar scan of workshop participants on.
As part of the workshop registration process, participants were asked to complete a questionnaire designed to collect statistics regarding their use of TLS as a tool for conducting their research. The full participant survey results summary is provided on the UNAVCO website. A few highlights from these survey results that illustrate the workshop participants is provided below.

Participants indicated they currently use TLS to support the following applications:

- 88% Geoscience
- 13% Cryosphere
- 27% Engineering
- 17% Ecology
- 12% Anthropology
- 10% Other (specified as transportation, education, historic preservation, space-planning, forensics, physics, ballistics, visual effects and air pollution.

Approximately half (49%) of the workshop survey responders had previously utilized UNAVCO resources. Other community resources had also been utilized at various levels.

- 49% UNAVCO
- 15% USGS
- 10% OPEN TOPOGRAPHY
- 9% NCALM
- 8% INTERFACE besides UNAVCO
- 8% CRREL

Many responders had not used any of the above community resources (25%), and many (9%) indicated they were not aware of any community TLS resources prior to the workshop.

**Findings and Recommendations**

Four primary areas of TLS requirements and recommendations emerged from the presentations, breakout sessions and group discussions. These were 1) products, 2) metadata, 3) training and 4) support. Presented below are the cumulative and “non-controversial” findings and recommendations on these four topics. These findings and recommendations were the product of several different breakout groups addressing identical topics for each breakout session. In addition, each group was lead by different moderators each time. Despite the distributed nature of the processes, all groups in each session reached similar conclusions as did the entire assembled group during the final plenary session. Hence the process lead to convergence of ideas and agreement on the issues and opportunities. For that reason, the recommendations listed below should be considered as having resulted from clear and overwhelming consensus of the workshop participants.
**Products.** Products are the data or something derived from the data. As such, they are somewhat tiered in that some results depend on producing products to then manipulate or analyze. In this way, we can think of products as having levels. Note that at higher levels (e.g., DEM or textured mesh) there may be several products derived from the same underlying data at a certain degree of processing and manipulation. This is independent of the equipment to gather data, but rather describes classes of data collected and level analyzed.

**HOW DO WE DESCRIBE THE PRODUCTS?**

It was recommended that TLS data levels and formats should be identified and implemented in a manner analogous to GPS data as much as possible. There is a clear need for a sensor-independent common exchange format that will allow the generation and regeneration of higher level data products. The definition and format of low level data products is ultimately in the hands of the instrument manufacturers but the community, through UNAVCO, NCALM, CRREL and other organizations should communicate with and work with the industry leaders on this goal. Higher level, derived product formats can be defined and standardized by the support facilities. Examples of data product level definitions are as follows.

- **Level 0.** Raw sensor data. This will be in multiple formats for each of the different instruments used in TLS data collection, e.g., TLS, GPS, camera, Total Station, etc. These will not necessary be easily accessible to general programs but should be archived and available for all datasets.

- **Level 1.** Sensor data in accessible format with sufficient metadata to further process the information. This will include both single return as well as multiple return or full waveform data. Level 1 data typically represent a single scan from a single scan position. Data should be stored in “Rinex equivalent” format such as E57 (LAS, IXF, ASCII are widely used but not ideal). Observables should include at least: X,Y,Z, intensity.

- **Level 2.** Merged and aligned point cloud data. The point cloud may or may not be georeferenced. Level 2 data typically represent all relevant scans from a project including multiple scans and scanpositions if they exist. Data should be stored in “Rinex equivalent” format such as E57 (LAS, IXF, ASCII are widely used but not ideal). Observables should include at least: X,Y,Z, intensity.

- **Level 3.** Higher-level data products. Derived products such as classified point clouds (e.g., points classified as ground vs. vegetation), DEMs, shaded relief, full 3D mesh or surface, and textured surfaces (meshes with texturing from associated photography or other sensor). It is anticipated that data at this level will have been somewhat decimated, so metadata clearly describing both processing and data loss are critical.
• Level 4. Final results. This may be a more complex model with scientific or technical interpretation. Final publications fit at this level. Hydrologic model, difference result.

**Metadata.** Metadata is the essential information needed to use the data. This is variable, and depends again on the desired product level. In addition, metadata is critical in the integration and interoperability of products/data with other data sources of the same type (TLS) or different collections.

**WHAT IS NEEDED FOR EACH PRODUCT, PROVENANCE, AND MODELING PACKAGE?**

Proper metadata and best practices are essential to go from one data level to the next. Metadata should be in a standardized format such as E57. Metadata standards should be developed and implemented by the community and be a requirement for all archived datasets. Users must submit instrument metadata documentation for archiving. There should be required metadata elements for all projects as well as optional elements depending on survey type. It was suggested that existing UNAVCO, NCALM and USGS project reporting documents can be used as a starting point for current and future efforts. IPADs and other field metadata recording system can be utilized to facilitate and ensure metadata collection. Recommended minimum required metadata is summarized below.

Data acquisition (field) metadata.
- Scanner make, model, serial number, firmware version.
- External camera make, model, serial number, lenses used.
- Reflector/target description and number used.
- GPS make, model, serial number, firmware version.
- Meteorological sensor make/model.
- Tripod type.
- Other instrumentation used.
- Notes/maps/drawings of project field site, scan positions, tiepoint locations, emphasis on what the primary objects of interest were. Following should be clearly identified and described: objects of interest, desired resolutions and real world arc angles; reflector/targets; scan positions; GPS sites; etc.
- Description of control points/strategy.
- Data acquisition software and version used if applicable (i.e. Riscan Pro, Cyclone, etc.)
- Weather conditions throughout survey (barometric pressure, temperature, humidity, wind, snow, etc.)
- Names of field crew / project team.
- Absolute time of scans.
- Maps of site and access to site (land owners, contacts, etc.).
- Photos of scan positions, targets, etc. (independent from photos acquired for true color imaging of lidar data).
Any conditions or events that may have affected data (e.g. tripod moved/kicked during scan, power failure, hardware/software errors, wind gust, noise from birds/dust/fog, tiepoint problems, etc.).

Data processing metadata.
- Software used.
- Intricacies of tying control.
- Decimation scheme.
- DEM computation scheme.
- Classification scheme.
- Error estimates/analysis.

**Training.** Training is conveying the knowledge or skill set to produce a certain product. In this sense, training is tiered with products, but someone knowing how to create one level of product need not know how to produce either lower or higher level products. The example is that many workers know how to create DEM’s (a product that depends on several other products), but have no knowledge or skill in collecting a point cloud. Training can be viewed as a workflow or cookbook that can produce a single data product or span the realm passing across several hierarchical/dependent data products. Training is imparted to the users and practitioners of the method. One aspect is what is needed for someone establishing this as primary research methodology vs. a “one-off” project.

**WHO TRAINS AND HOW ARE BEST PRACTICES ESTABLISHED?**

Workshop participants agreed that there is overwhelming demand for community training opportunities in TLS data analysis procedures and best practices. Training should capitalize on best practices guidelines. There should be recommended procedures for obtaining various levels of accuracy, and the acquisition protocol must be guided by the science question being addressed. There should be tutorials and “cookbooks” available. It was suggested that it would be useful to develop online training modules with “certifications” such as is done for helicopter training, safety training, etc. It was also emphasized that there should be strong feedback between data acquisition and processing training. It was recommended that training be provided in the following areas.

- Data acquisition (instrument operation). It was agreed that for most individual “one-off” scanning projects it makes the most sense for an experienced, qualified operator (i.e. UNAVCO field engineer) do the data gathering in most cases. However, UNAVCO and other instrument providers should provide training for PI’s to collect data themselves when appropriate. Training in best practices should emphasize need for accurate geo-referencing of lidar data; while collecting geodetic quality GPS data for geo-referencing can make a TLS project more logistically challenging it was agreed that ANY scanning project is potentially a re-scanning site and therefore accurate geo-referencing should be
standard procedure. Data acquisition training should cover the generation of data product Levels 0 through 2 (raw sensor data to merged, aligned, geo-referenced point cloud). Instrument training is most effective for small groups of learners (<5 people) and should include real field experience.

• **Data Processing and analysis.** There was strong universal support for TLS short courses such as those done through UNAVCO for InSAR, strain, ALS, GPS, etc. Data processing and analysis training should cover the generation of Level 3 data products and higher. Short courses are most effective for small to medium sized groups of learners (10-30 people). There should be online training modules and reference materials. Training should cover the following topics through various courses and online resources:
  o Software recommendations.
  o Software licenses.
  o Computer hardware specs and recommendations.
  o Mechanics of installing software and getting computer set up.
  o Instructions and best practices for going from a point cloud to a surface.
  o Best practices for DEM creation using common tools (surfer, Arc, GMT, P2G, etc.)
  o Integration with ArcGIS tools.
  o 3D virtual geology, i.e. textured meshes.

• **Data exploration, education and outreach.** There should also be short courses and workshops for users who don’t want to process the data but who want to use data in education, classrooms, etc.

• **User-to-user training and networking.** It was recommended that there should be mechanisms for sharing knowledge within the community besides formal classes. One way to do this is to set up user forums such as those on the USGS CLICK website. Another way is for PI’s to extend invitations for interested people to participate in their field projects to gain first hand experience on a real project.

**Support.** Support describes how the TLS community assigns responsibility or effort to describing metadata, giving training, or serving products. This applies at all levels of data and effort. In addition, this also assigns responsibility for instrumentation and archiving of data. This is very heterogeneous in that it involves facility, PI, and broader community participation.

**WHAT SUPPORT RESOURCES ARE REQUIRED AND WHICH GROUP(S) ARE “GO TO” FOR EACH OF THE ASPECTS OF TLS?**

The following support services are required from UNAVCO and/or other groups:
• Instruments (a diverse, well maintained and up-to-date pool).
• Field engineering support.
• Instrument QA/QC resources (calibration facilities, data quality standards, etc.).
• Best practices guidelines.
• Helping define standards.
• Organize meetings, workshops, short courses.
• Voice community concerns to vendors.
• Data management resources (e.g. RAMMADA).
• Data archive (permanent repository).
• Data clearing house (dissemination).
• Data processing resources (e.g. computers and software)
• Education and outreach.

Several highly complementary groups were identified and recommended for providing and/or developing the community support resources just described. Consideration of presently funded NSF facilities – UNAVCO, Open Topography and NCALM – led to the following recommended distribution of support resources for NSF funded PI’s.

UNAVCO should be the primary NSF facility and initial point of contact for supporting TLS data acquisition and archiving. UNAVCO provides the following TLS PI support: proposal planning, project planning, instrumentation, field engineering, data archiving, training, and access to data processing hardware and software. Instrumentation provided by UNAVCO has greatly lowered the barrier to scanner availability. UNAVCO is also a nexus for community activities such as this workshop and INTERFACE, and supports education and outreach efforts on multiple scales. The appropriate standard UNAVCO data level deliverable to supported PI’s is at the point cloud level (i.e. merged, aligned, geo-referenced point cloud) or Level 2 in the product description above.

UNAVCO should establish the language and reporting procedures for meeting NSF data plan and reporting requirements. UNAVCO should aim to support community volume purchasing. In order to properly support PI’s in addressing diverse science questions, it is recommended that UNAVCO work with sponsors to maintain and expand its instrument pool as appropriate to keep up with community needs and new technologies. Looking forward, it is recommended that UNAVCO acquire new instruments with the following capabilities to enhance the current pool:

• Longer range TLS (>2 km).
• Full waveform TLS.
• Snow and ice optimized TLS (long range, 1064 nm wavelength).
• Terrestrial radar.
• Phase shift TLS (short range, high rate).
• Water penetrating TLS.
• XBOX Kinect short range scanning (http://www.idav.ucdavis.edu/~okreylos/ResDev/Kinect/)

In addition to maintaining and expanding instrument resources it is also highly recommended that UNAVCO supporting the following aspects of instrument deployment:

• Standardized calibration and validation facilities and procedures.
• Best practices guidelines for instrument use and data acquisition.
• Realistic error analysis for various instruments and data acquisition practices.

UNAVCO should provide the following computer and software resources to allow PI's to manage, process and analysis data acquired using UNAVCO equipment:
• Server that allows PI's to process data and access software and necessary licenses remotely.
• Metadata standards and capture tools.
• NSF project tools (data management and compliance).

OPEN TOPOGRAPHY should be the primary NSF facility for supporting TLS data dissemination. OPEN TOPOGRAPHY is an NSF facility funded between EAR and OCI. Their goal is to increase the amount of Earth Science oriented TLS that is readily and easily available. OPEN TOPOGRAPHY has tiered data access and a broad range of download and processing capabilities. In addition, they maintain the OPEN TOPOGRAPHY tool registry.

NCALM should be the primary NSF facility for supporting mobile platform scanning (cars, aircraft, etc.) data acquisition and archiving. NCALM is primarily known as a resource for research quality airborne LiDAR data but they also support TLS data acquisition, processing and analysis as well as research and development oriented activities. NCALM also have experience developing and applying bathymetric LiDAR measurements, and have several higher-level sensors such as cameras and hyperspectral imaging systems that can be integrated with laser scanners. NCALM also have Mobile Laser Scanning (MLS) capabilities. Most of the TLS and MLS instruments available through NCALM are owned by the University of Houston, one of NCALM’s host institutions.

There should be good communication and integration among the NSF facilities to support PI's at the highest level of service possible. There should be an NSF data management plan and policy for inclusion in PI proposals and to help guide data access to the community. NSF facilities should continue to maintain strong relationships and collaborations with federal agencies such as the USGS, CRREL and USDA and with PI’s in the geosciences and related fields including ecology, anthropology and engineering communities.

The U.S. Geological Survey is recognized as a key resource for TLS technique development, science and expertise as well as data resources such as via the CLICK facility. CRREL (Cold Regions Research and Engineering Laboratory) is established as a remote sensing and GIS center of expertise involved in research, applied science, and technology transfer. They are a resource for expertise and collaborative efforts and have several TLS units as well as cameras and sensors including thermal imaging. Another federal agency represented at the workshop was the U.S. Department of Agriculture.
The PI’s of the NSF funded INTERFACE project continue to provide community support through their own institutions in addition to UNAVCO as well. Indeed the findings from this workshop have inspired potential future INTERFACE endeavours.

- University of Texas at Dallas (John Oldow, Carlos Aiken)
- University of Kansas (Doug Walker)
- Arizona State University (Ramon Arrowsmith)

Numerous PI’s and university-based groups are also recognized as being important community TLS resources and points of expertise. These include:

- University of Hawaii (Ben Brooks)
- University of South Florida (Lori Collins)
- Idaho State University (Nancy Glenn)
- University of Idaho (Lee Vierling)
- Colorado School of Mines (Keith Turner)
- Western State College of Colorado (Tim Wawrzyniec)
- UC Davis (Eric Cowgill)

It is recommended that the above groups develop a list and process for sharing and requesting resources, especially instruments. For example UNAVCO should be the starting place for NSF PI’s to request TLS project support but UNAVCO would redirect requests as needed or appropriate to collaborating support providers such as INTERFACE and other university PI’s, NCALM, CRREL, USGS, etc.

It is suggested that facility-led opportunities for students like the “seed grant” program provided by NCALM would be of great interest and would help grow and diversify the community.

Finally it was emphasized that TLS is one “band” of the terrestrial geodetic imaging “spectrum” and that the community, facilities and sponsors must strive to achieve and maintain a holistic mixture of TLS, ALS, radar and photogrammetry.

**Conclusion**

This workshop was remarkable for the number of participants, the energy and enthusiasm of the participants, the collaborative spirit of support facilities and providers, and the emergence and convergence of non-controversial recommendations to enable forward progress, that is “charting the future”. The proceedings, findings and recommendations from this workshop will help build a stronger, more capable, more organized and more effective terrestrial geodetic imaging community.
Appendix A

Workshop Agenda
The itinerary below shows the planned flow of sessions and activities, though the start and end times for individual sessions may be updated “on the fly” to best meet the goals of the workshop and participant interests. The Science Applications sessions will be comprised of several 30-minute oral presentations showcasing a wide variety of TLS projects. All other sessions will include a small number of presentations followed by breakout groups and group discussions designed to stimulate open dialog and constructive recommendations. Breakout sessions will deal with specific questions and will report back to the group for discussion and synthesis. Evening sessions will include poster presentations, TLS instrument demonstrations and informal breakout sessions.

**Monday, October 17 – 8:00am - 9:00pm**

7:00 - 8:00  Breakfast ........................................................................................................... Ballroom A/C
8:30- 9:15  Welcome, introductions and charges for the workshop and day .................. Ballroom B/D

**Session I: Science Applications**

9:15 – 10:15  **Presentations** ............................................................................................. Ballroom B/D
Use of terrestrial laser scanning (TLS) and synthetic aperture radar (SAR) to characterize, monitor and estimate above ground vegetation biomass in the Florida Everglades .......... E. Feliciano, U. Miami
TLS applications in paleoseismology ................................................................. D. Haddad, Arizona State U.
10:15 – 10:30  Break
10:30 – 12:00  **Presentations** ............................................................................................. Ballroom B/D
Transformative glaciological applications using TLS............. L. Stearns, U. Kansas & D. Finnegan, CRREL
TLS observations at the active Erebus volcano, Antarctica............... J. Frechette, U. New Mexico
2011 Japan tsunami measurements using TLS................................. H. Fritz, Georgia Tech
12:00 - 1:00  Lunch ............................................................................................................. Ballroom A/C
1:00 – 1:10  Group Photo and Group Scan ................................................................. Location TBD

**Session II: Data Processing, Analysis & Visualization (software, workflows, deliverables)**

1:10 – 3:00  **Part I: Presentations** .................................................................................. Ballroom B/D
Assessment of uncertainty budget in TLS characterization of fault scarps.............. J. Oldow, UT Dallas
TLS landslide geodesy: From point clouds to sub-surface slip distributions.......... B. Brooks, U. Hawaii
Introduction to mobile laser scanning: Current applications and state of the art ...... C. Glennie, U. Houston
High resolution photorealistic outcrop model acquisition, construction, analysis ...... L. White, GHV Models
3:00 – 3:15  Break ............................................................................................................. Ballroom A/C
3:15 - 5:00  **Part II: Breakout Groups and Open Discussions** ........................................ Ballroom B/D, Rooms 231, 331, 431

**Evening Session**

5:30 – 6:30  **Dinner** ........................................................................................................... Ballroom A/C
6:30 – 7:30  **Part I: After Dinner Keynote Presentation** .................................................. Ballroom A/C
   Ultra-High Resolution Four Dimension Imaging Across the Earth Sciences .......... G. Bawden, USGS
7:30 – 9:00  **Part II: Posters, Demonstrations and Informal Breakouts**
Posters ......................................................................................................................... Millennium Room
Instrument demonstrations ....................................................................................... Ballroom B/D
Informal breakout discussions ................................................................................... Rooms 231, 331, 431
Tuesday, October 18 – 8am – 9pm

7:00 - 8:00  Breakfast .................................................................................................................. Ballroom A/C
8:00 - 8:15 Welcome and charge for the day .............................................................................. Century Room

Session III: Data and Metadata (standards, formats, archiving and distribution)
8:15 – 10:15  Part I: Presentations ................................................................................................. Century Room
The evolution and current state of GPS data formats and metadata ............................. A. Borsa, UNAVCO
LiDAR data handling lessons learned and perspective from the USGS ......................... J. Stoker, USGS
Overview of libLAS & PDAL (pointcloud.org), LasZIP ..................................................... D. Finnegan, CRREL
The RAMADDA data repository framework ................................................................. J. McWhirter, UNAVCO
ASTM E57 ............................................................................................................................. A. Fowler, Reigl
Industry perspective ............................................................................................................. A. Fowler, Reigl; T. Woodruff Leica; A. Pelkie, Optech

10:15 – 10:30  Break ....................................................................................................................... Ballroom A/C
10:30 - 12:00  Part II: Breakout Groups and Open Discussions .............................................. Century Room, 231, 331, 431
12:00 - 1:00  Lunch ......................................................................................................................... Ballroom A/C

Session IV: Community Resources (existing, required, desired)
1:00 - 3:00  Part I: Presentations ................................................................................................. Century Room
UNAVCO community resources .................................................................................... D. Phillips, UNAVCO
NCALM community resources ...................................................................................... C. Glennie, U. Houston
OPEN TOPOGRAPHY community resources ................................................................. C. Crosby, USCD
CRREL community resources ......................................................................................... D. Finnegan, CRREL

3:00 – 3:15  Break ....................................................................................................................... Ballroom A/C
3:15 - 5:00  Part II: Breakout Groups and Open Discussions .............................................. Century Room, Rooms 231, 331, 431

Evening Session
5:30 – 7:30  Dinner ..................................................................................................................... On Own
7:30 – 9:00  Posters, Demonstrations and Informal Breakouts
Posters ................................................................................................................................. Millennium Room
Instrument Demonstrations ............................................................................................. Century
Informal breakout sessions ............................................................................................... Rooms 231, 331, 431

Wednesday, October 19 – 8am – 12pm

Session V: Charting the Future (community building, resources, products, recommendations)
7:00 - 8:00  Breakfast .................................................................................................................. Ballroom A/C
8:00 - 12:00 Discussions, breakouts and closing comments ......................................................... Ballroom A/C
12:00 - 1:00 Light Lunch ............................................................................................................. Ballroom A/C
1:00 - 5:00 Report Writing by Organizing Committee ................................................................. Ballroom B/D
Optional afternoon activities (e.g. tour of UNAVCO Facility or scanning demonstrations)
Appendix B

Workshop Registrants
# 2011 Terrestrial Laser Scanning (TLS) Workshop

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