

Integrated Monitoring Protocol for Cave Entrance Communities and Cave Environments in the Klamath Network

Standard Operating Procedure #6: Ice

Version 2017Feb10

Citation:

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To create a new version of this SOP, carefully follow the instructions in SOP #18: Revising the Protocol (<https://irma.nps.gov/DataStore/Reference/Profile/2238840>). Use the Revision History Log below to describe the revisions:

- Populate the top table of the revision history log, providing the previous version date, author of the change, a specific but concise description of the changes made, the footnote number associated with change details, and a new version date.
- In the bottom table, add a footnote and as much text as needed to describe in detail the reasons for and implications of the change.

Revision History Log

Previous Version Date	Author of Change	Changes Made	Footnote #	New Version Date

Footnote #	Detailed Reasons for and Implications of the Changes

1 Introduction

This Standard Operating Procedure (SOP) provides guidance for setting up ice monitoring stations, conducting ice monitoring in caves, and processing the monitoring data using GIS. Ice resources are a major concern at Lava Beds National Monument (LBE), where it appears that ice bodies are rapidly retreating in many caves. Ice buffers cave temperatures; a reduction in ice leads to higher temperatures, which accelerates the melting of more ice, potentially creating a positive feedback loop. LBE will be responsible for monitoring ice each year. Ice is monitored in 4 ways: (1) photomonitoring, (2) measuring plumb bob distance from permanent stations, (3) conducting laser distance meter transect surveys, and (4) conducting laser distance meter perimeter surveys. Each of the quantitative methods (2–4, above) involves tying in to permanent stations in the cave wall that have a known elevation (feet above mean sea level). These distance measurements provide a quantifiable way to record changes in ice levels relative to surveyed stations and are already in use at the park. The area of the ice will be measured using a laser distance meter mounted on a tripod. By taking repeated measurements of the distance and inclination from the distance meter to the edge of the ice, the area of the ice can be calculated using ArcGIS. Over time, changes in ice area and depth can determine approximate ice volume change.

Clear and concise descriptions for the location of cave specific landmarks monitored are necessary for successful implementation of this SOP. Information on the landmarks and relocating them is provided in the cave site dossiers, which are referenced in Appendix C: Examples of Cave Site Dossier Materials. Many of the tasks associated with the monitoring rely on cave specific information contained within the site dossiers. The crew should become familiar with the site dossiers and print out relevant portions for the site visit.

Note this safety and quality concern: crews work in temperatures at, near, or below freezing. Crews should dress appropriately to a) prevent hypothermia, and b) allow relative comfort so that they are not rushed in the tasks and accidentally skip or botch measurements.

2 Equipment

- Dedicated and/or decontaminated caving equipment, including: helmet with mounted light(s), backup lights, kneepads, gloves, boots, park radios, and any additional safety items
- Warm clothes for extended monitoring time in freezing temperatures
- Cave zone maps
- Ice Monitoring Datasheet (available at end of this SOP)
- Photo Data Sheet (available from SOP #14)
- Pencils
- Watch
- Compass and inclinometer for orienting camera at photomonitoring sites

- Olympus EPL-5 Camera with 14-42mm lens
- Olympus FL-600R Flashes (2) for remote discharge
- Extra batteries for camera (rechargeable) and flashes (AAs)
- Large memory card (32GB) for camera
- Camera mounted bubble level for precise orientation of camera
- Metric tape measure
- Black and white PVC meter stick with alternating colors every 0.10 m (used as in-cave scale bar for photomonitoring)
- Plumb bob
- Laser Distometer (Leica Disto D8 or DistoX2), and target card marked in centimeters
- Leica Tripod with 10 degree hatch marks with Leica TA360 tripod adapter for Disto or Laser Technology Inc. #7024901 non-magnetic tripod and ball-head
- Laptop (or pocket PC) for collecting data from Disto D8 or DistoX2 (datasheet can be used as backup method for data collection)
- Waterproof boots capable of remaining dry in water up to 3 inches deep
- Optional boot “micro-spikes” for caves that require travel over ice-covered inclines or rime-coated breakdown
- Transect reference information from previous monitoring efforts
- Photomonitoring reference images and descriptions
- ArcGIS or other software for generating polygons and calculating areas/volume change over time.

3 Timing

Ice monitoring will occur each March and October. This will provide some information on the seasonal fluctuation of ice/water levels, as some ice often melts during the summer. Timing of individual cave surveys should match the timing of previous cave surveys, preferably within 3 calendar days, and no more than 10 calendar days. For example, if a cave was originally sampled on March 10, 2016, it should be resampled between March 7 and March 13, and not outside the date range of March 1 to March 20, 2016. This should be based on the original survey date of the cave rather than on the most recent survey (so that “creep” over time does not slide sampling dates even further apart).

4 Locations

Table 6-1 lists the caves where ice monitoring will occur at Lava Beds National Monument.

Table 6-1. Five ice caves monitored at Lava Beds National Monument..

Cave Name/Code
CAIC
COIC
Big Painted Cave/BIPA
Crystal Ice Cave/CRIC
Skull Ice Cave/SKIC

5 Instructions

5.1 Creating Ice Monitoring Stations

Ice monitoring requires the establishment of 3 types of stations: (1) a permanent landmark(s), (2) photo point locations, and (3) tripod points for the distometer (Disto).

Park staff will mark new ice monitoring stations with small, inconspicuous aluminum nails and tags etched with the station number and affixed by epoxy into a drilled hole in the cave wall, ceiling, or floor; these are the permanent landmarks (Figure 6-1). Aluminum nails and tags are non-magnetic, and will therefore have no influence on magnetic compass readings. At staff discretion, unambiguous natural features may instead be used as a permanent landmark when the cave provides such a feature, but these must be stable, permanent features, and they require clear documentation so that they may be relocated.

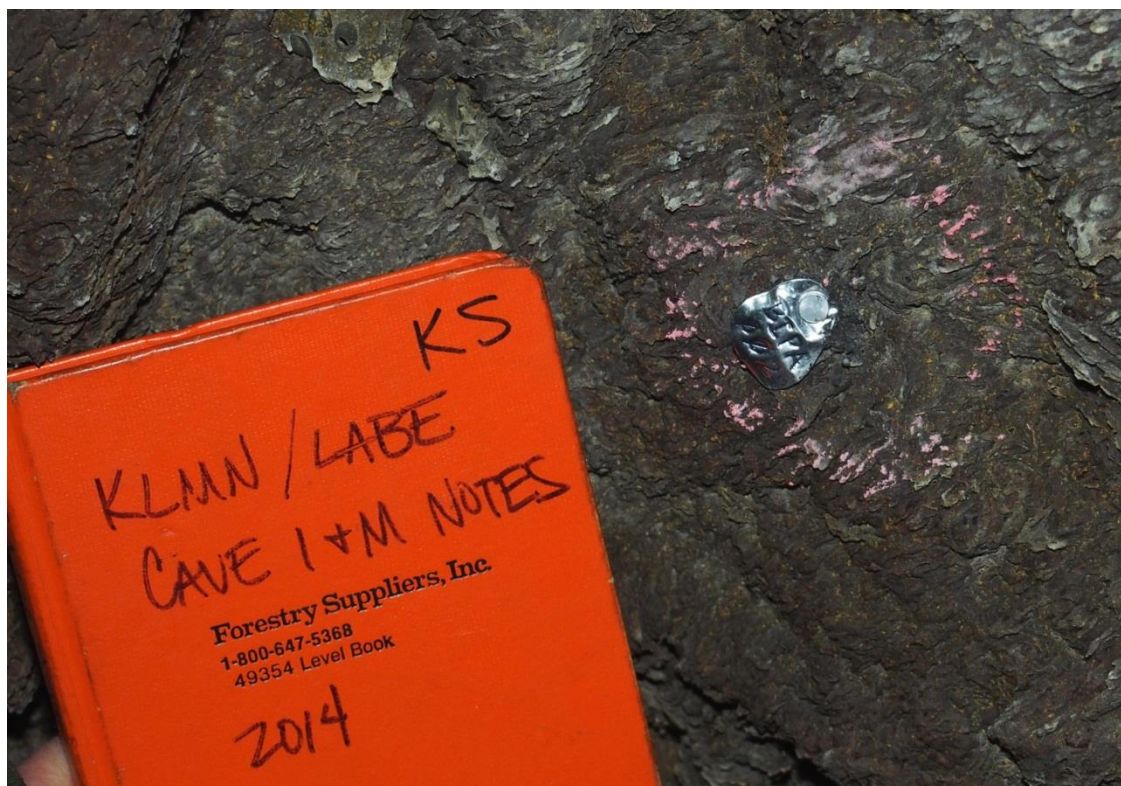


Figure 6-1. Labeled aluminum ice monitoring station mounted in cave ceiling, with notebook for scale.

Because ice deposits vary in size, cave personnel will determine exactly how many monitoring stations should be installed. At least 1 and as many as 10 landmark stations will be created, located at least 1 m apart. This will help ensure that landmarks remain useful even if ice deposits retreat, advance, or show differential melting. Cave morphology, ice location, and efforts to keep landmarks inconspicuous will dictate where the landmarks will be located. Whenever possible, existing landmarks will be used. New landmarks will be utilized for as many of the 4 ice monitoring methods as possible in order to minimize the number of permanent landmarks added to the cave.

For photo points, where feasible, a permanent landmark will be installed in the ceiling or floor above or below the camera tripod location. Distance from the top of the camera lens to the station will be measured, allowing for fast relocation of photo points in cold cave conditions. If not feasible, the photo point will be described relative to other landmarks (e.g., azimuth, inclination, and distance). Information will be recorded in the cave site dossiers, which are referenced in Appendix C: Examples of Cave Site Dossier Materials.

For plumb bob distance measurements, the landmark(s) will be placed where a vertical line from the nail and tag intersects the ice deposit. Landmarks will be located so that a tape measure can be used to measure the distance between the point and ice deposit. Historical data have been collected using this method since 1990; this protocol continues those measurements in order to maintain consistency with that long-term dataset. At least one plumb distance measurement per ice deposit is recommended, and the landmark may also be used for photo points or tripod points.

Tripod points, which correspond to the transect and perimeter surveys, should be placed in approximately the same location as in previous year surveys to ensure consistent line of sight to as much of the ice perimeter as possible. Transect measurements will utilize the same tripod points. If ice deposits change significantly, the tripod location may be relocated to best fit the new conditions. By surveying a tie-in shot from the current tripod location to permanent landmarks, ice measurements continue to be referenced to the permanent landmark point in space regardless of how significantly the tripod location must be moved.

5.2 Photomonitoring

The objectives of photo point monitoring are to capture details of the ice formations that are not measureable by perimeter or transect surveys (holes, frozen waterfalls, icicles, or mounds of ice), to clearly document the perimeters of the ice deposit in relation to recognizable features of the cave passage, and to portray the overall “feel” of the volume of ice within the passage. The number of photo points per cave varies depending on the size and shape of ice deposits, but each cave has a minimum of 3 photo points marked with an aluminum tag and a station number (as in Figure 6-1, above).

A tripod should always be used when taking photos to ensure image quality and to assist in accurate reframing to match previous photos (Figure 6-2). An on-camera bubble level should be used when setting up the photo point to ensure that photos are level. The inclination of previous photos is documented in the cave site dossiers, which are referenced in Appendix C: Examples of Cave Site Dossier Materials. Flashes should be used in approximately the same locations and with the same power settings as per previous efforts, also recorded in the site dossiers, though varying ice levels and conditions may dictate that settings and positions are tailored to individual efforts.

An in-photo scalebar should ideally be used to aid in visual analysis of the photographs. A one-meter-long PVC pipe “meter stick,” with alternating black and white 0.1 m segments is ideal. Its location should be the same as in previous photographs, and locations should be chosen such that the scale bar helps to gauge the size of cave and ice features. Likewise, when people are in previous images, they should ideally be in the same location and pose.

Prior to field visits, the crew should become familiar with the currently used camera, tripod, level, and flashes to ensure adequate ability to recreate photos in the cave. Different images in the cave will necessitate changing manual settings on the camera; therefore, the crew should know how to manually adjust 1) ISO, 2) F-stop, 3) exposure time, 4) exposure bias, 5) aspect ratio, and 6) lens focal distance and CCD (image sensor) size ratio. They should do a trial of the setup in a dark room or comfortable cave (e.g., not a freezing ice cave). Though the currently used Olympus FL-600R flashes have infrared remote slave capabilities, they can be difficult to configure correctly and inconsistent in their reliability underground; a workaround is to photograph using a several-second exposure time, while manually triggering each external flash.

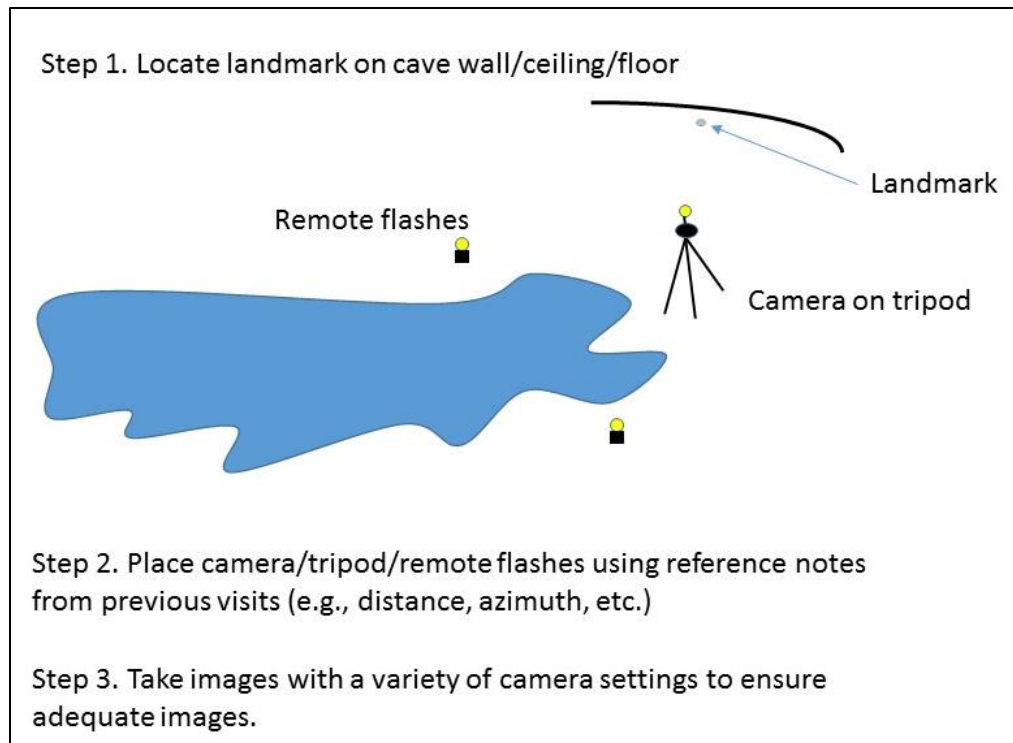


Figure 6-2. Photo point setup for cave ice monitoring, with instructions for finding the landmark, setting up the camera, and taking the image.

Camera settings that should be adjusted to match previous photos are:

- ISO
- F-stop
- exposure time
- exposure bias
- aspect ratio
- lens focal distance and CCD size ratio

The crew should take adequate photography notes during each visit to facilitate rapid retaking of the photos in the future. Metadata should be recorded following the guidelines in SOP #14: Photograph Management.

Currently documented photos are presented below in Table 6-2. Prints of previous reference images should be brought during each visit to help with the replication of images.

Table 6-2. Required images for photo point monitoring at the 5 ice cave locations. Note that CRIC photo IDs have been inherited from a prior long-term photo monitoring program specific to that cave.

CAIC	CRIC—Crystal Ice Cave
Looking At Hole	4.1-20 (Entrance Slope)
Looking At Wall	5-270 (Entrance Column-2 photos)
Looking Down Passage	8-220 (Side Passage Icicle Left)
	8-260 (Side Passage Icicle Right)
COIC	9-220 (Side Passage End Feature)
Back Wall Left	3.1 (4 th Floor Crystals)
Back Wall Center	2.1B (Red Ice Room-2 photos)
Back Wall Right	6.1A (Lower Floor Travel Path Glaze)
Looking At Entrance	7.1 (Lower Tube In Tube)
Looking Down Passage	9A-225 (Lower Floor)
	10.1A-170 (Lower Column)
SKIC—Skull Ice Cave	10.2A-350 (Lower Drapery and Glaze)
Front Room Left	12.1A (Lower Level Pano-7 photos)
Front Room Center	16A-30 (Backside Lower Level Draperies)
Front Room Right	19A-180 (The Blue Glacier)
Front Room Back	
Striated Wall	BIPA—Big Painted Cave
Boneless Cavern Left	Big Pool Right
Boneless Cavern Right	Big Pool Left
Boneless Cavern Waterfall Left	Small Pool
Boneless Cavern Waterfall Right	

5.3 Plumb bob distance

The technicians will locate the monitoring stations and use a plumb bob to ensure that the measuring tape is vertical while measuring the distance from the screw to the ice surface (in meters, to centimeter accuracy (e.g., X.xx meters). If there is a layer of water on the ice surface, the distance to both the water and to the ice will be recorded (Figure 6-3).

Any noticeable changes in the ice structure should be documented in the comments field on the datasheet, such as the development of holes or rivulets in the ice or major expansions of ice fingers.

If ice retreats or grows such that no landmark stations are directly above the deposit, a new station should be placed above the ice. Staff familiar with cave survey techniques using a compass and inclinometer, similar to those described by Dasher (1994), will then survey from the original

station(s) to the new one. The survey should be repeated to ensure accuracy. With an accurate survey, the vertical distance between the screws can then be obtained so that the ice level relative to the original reference station can still be determined. This new survey should be as accurate as possible under Dasher (1994). If a new station is established, it should be recorded in the database and the Klamath Network Data Manager should be notified so that data can be adjusted accordingly. The addition of a new reference station and its location should be noted in the cave site dossier.

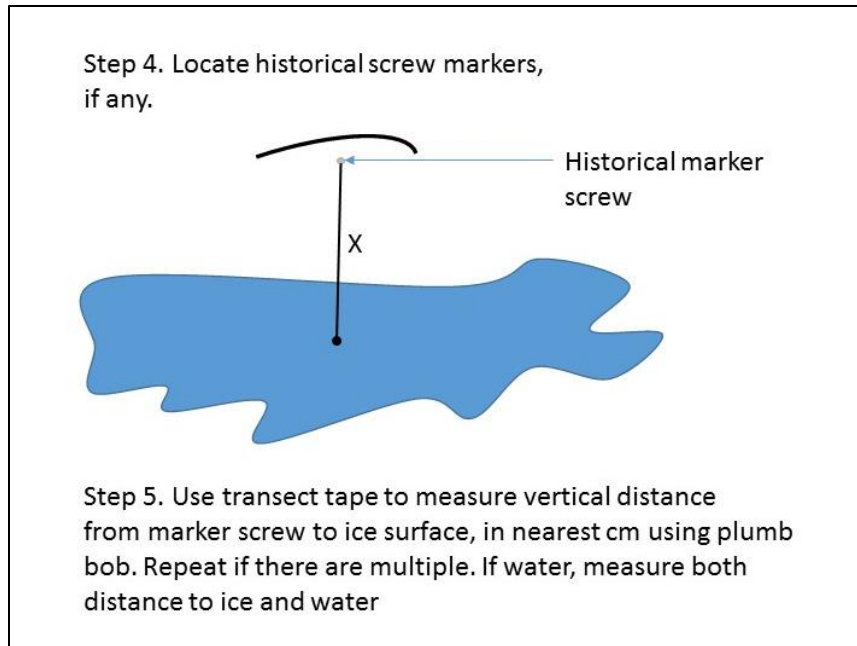


Figure 6-3. Plumb bob setup for cave ice monitoring, with instructions for taking measurements to the water (if any) and ice level.

5.4 Perimeter surveys

The area of an ice deposit is calculated with repeated measurements of the ice perimeter using a laser distance meter. A step by step description of how to use the distometer is beyond the scope of this SOP, and will change depending on model used. The owner's guide/manual should be consulted so that the crew is comfortable using the setup. We recommend trying the setup in a parking lot or picnic area prior to field use.

Ideally, the tripod point will be in the approximate center of the ice floor, and the distance meter will rotate 360° to record the distance and inclination to the edge of the ice (Figure 6-4). This placement will match approximately the same location as used for previous monitoring. To track back to previous visits, distance (to the nearest cm or X.XX m), azimuth, and inclination (to the nearest tenth of degree (e.g., X.X°)) will be measured from the distance meter to the relevant landmark in order to calculate the measuring position relative to the zero datum on each trip, using the distometer itself.

Starting at the reference landmark point, and incrementing clockwise at fixed 10° azimuth intervals, a total of 36 measurements (azimuth, distance, and inclination) will be recorded per ice floor (Figures 6-4 and 6-5). These fixed azimuth intervals are used to compensate for the lack of accurate magnetic

compass in most distometers (such as Leica Disto D8). If using the third-party modified DistoX2 distometer, along with a non-magnetic tripod and ball-mount, measurements may be taken at a finer resolution than 10° increments, so as to more accurately represent the irregular shape of many ice perimeters. Note that if an alternate method with finer resolution is used, a cross-walk comparison should be done at all ice-bodies (e.g., use both methods on the same monitoring visit). This will allow previous methods using 10° increments to be comparable to methods using finer resolution.

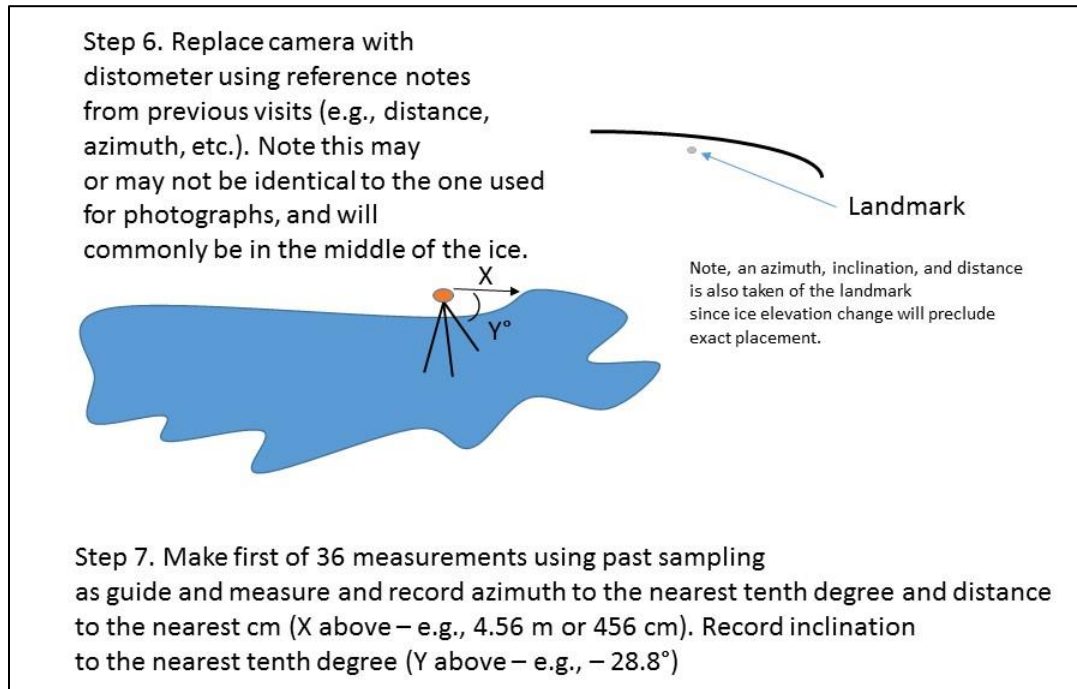


Figure 6-4. Perimeter survey setup for cave ice monitoring, with instructions for placing the distometer and initiating the survey.

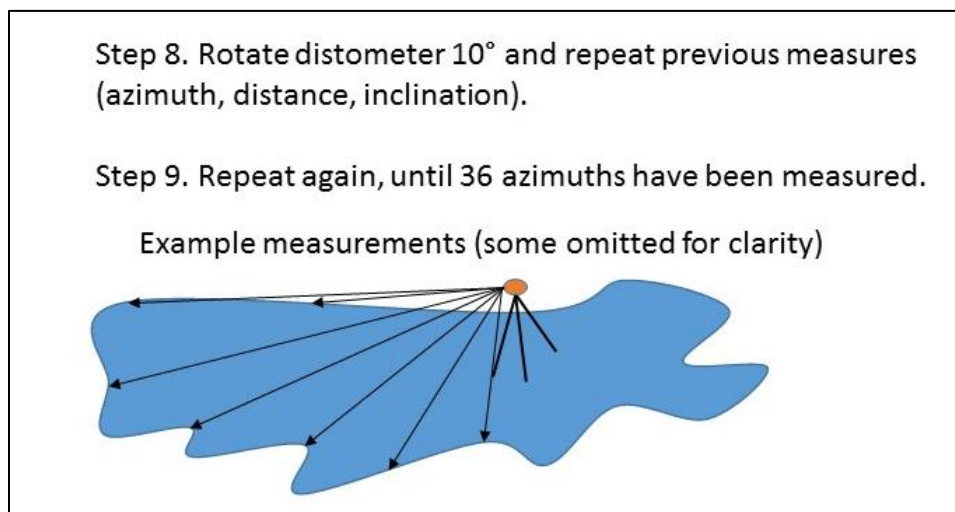


Figure 6-5. Perimeter survey setup for cave ice monitoring, showing rotation of the distometer every ten degrees to measure entire perimeter.

Irregularly shaped floors must be split into 2 separate perimeter surveys due to passage constrictions (for example, a “bowtie” shaped ice floor), and a total of 72 measurements will be recorded per floor (36 measurements per tripod location). In this case, a tie-in shot should be recorded from each tripod location to a reference landmark station so that the 2 individual surveys may be combined (Figure 6-6). Again, these situations are documented in the site dossiers.



Figure 6-6. Example of a “bowtie shaped” ice deposit that required 2 joined perimeter surveys for cave ice perimeter monitoring.

Finally, some ice surfaces may not be conducive to performing a survey from atop the ice itself, or a significant amount of water present may require that surveyors remain off the ice. In that case, a perimeter survey should be performed from a tripod location off the ice that affords line-of-sight to the entire perimeter (Figure 6-7). Starting from the reference landmark station, rotate clockwise as with a typical perimeter survey. Rather than rotating in a 360° circle, however, an off-ice survey will require that measurements change direction from clockwise to counterclockwise at least once while tracing the perimeter. Record this change of direction and each azimuth value explicitly for every measurement.

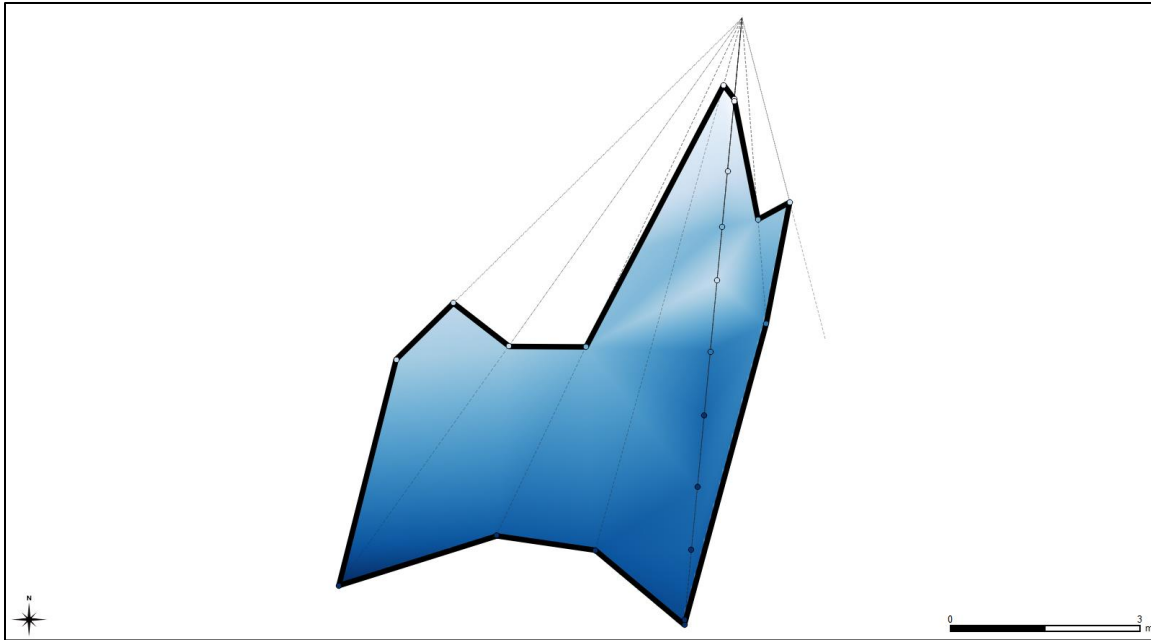


Figure 6-7. Example of an ice surface that required an off-ice perimeter survey for cave ice perimeter monitoring.

The data will be recorded on field datasheets, or sent, using Bluetooth, to the laptop or PDA and saved as a spreadsheet, to be uploaded eventually to the cave database.

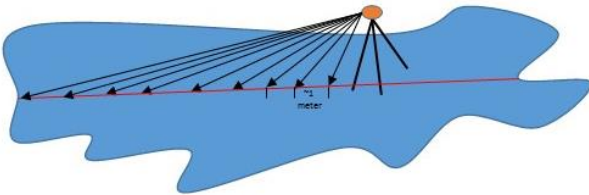
5.5 Transects

In addition to the perimeter survey, ice masses with significant surface variation may warrant one or more measurement transects. These transects can take one of two forms: (1) linear transects (Figure 6-8) in a straight line where the distance and inclination are taken at a fixed azimuth; or (2) in a curvilinear transect (Figure 6-9), where the azimuth is changed, but the inclination is fixed (e.g., at an inclination of 45.0°) and the azimuth and distance are recorded. Both methods allow the calculation of ice surface contours in GIS post processing.

If doing a linear transect, use the exact same tripod location as the perimeter survey, and choose a fixed azimuth providing a representative transect of the ice surface profile. Inclination and distance measurements to the ice surface are recorded as above, along the fixed azimuth, such that the horizontal distance between measurements is approximately 1 m.

If doing a curvilinear rotational survey at a fixed inclination, rotating at fixed azimuth intervals, select an appropriate inclination to capture the observed variation, and measure the azimuth and distance. This is again done using the exact tripod location as used for the associated perimeter survey.

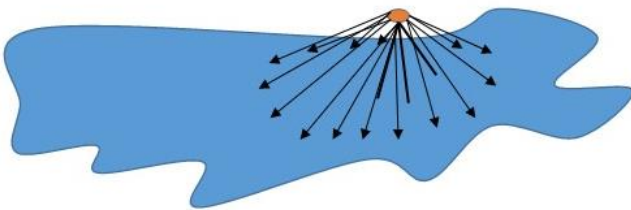
Step 9. If the ice body has a fixed azimuth transect for measuring variation in surface ice, set the azimuth based on initial visits (e.g., 150°)



Step 10. Measure inclination and distance in the transect so that spacing is approximately 1 m between points along the transect (red line). Record data to the same precision as the perimeter. Repeat at multiple azimuths *if warranted by an irregular ice surface.* (Ice changes seasonally and over time, so transects must also change).

Figure 6-8. Linear transect setup for cave ice monitoring, with instructions for measuring ice surface contour irregularities.

Step 11. If doing a curvilinear transect, select an appropriate inclination.



Step 12. Measure azimuth and distance along fixed azimuth intervals (10°). Repeat if necessary at a new inclination.

Step 13. Clean up, QAQC data, leave.

Figure 6-9. Curvilinear transect setup for cave ice monitoring, with instructions for measuring ice surface contour irregularities.

Multiple fixed linear and curvilinear azimuth surveys may be recorded. If the surface of the ice floor is fully covered in water, no transects need to be taken as the underlying ice surface is assumed to be perfectly level and can be interpolated from perimeter points; this should be reflected on the datasheets.

5.6 GIS Data Processing

The end result of the perimeter and linear or curvilinear transects (if no water was present), after trigonometric conversion, is a sparse X, Y, Z dataset in which points represent the surface of the ice in 3D space. This can be produced by standard cave survey data reduction software (e.g., Fountainware Compass). It is crucial that the zero-datum be consistent and defined across surveys, with elevation expressed in relation to an established landmark point for each ice body, so that all Z values are normalized with respect to that datum point, given that the tripod location will shift in location and elevation as the ice surface shifts over time.

Post-processing this dataset in the GIS domain produces a 3D raster representation of the ice surface (e.g., Figures 6-6, 6-7; simplified (no surface transects) in Figure 6-10), which can then be subtracted from a previous (or first baseline) ice surface raster to quantify net ice volume loss or gain. The following steps outline this post-processing workflow generically (the steps may be performed using QGIS, or ESRI's 3D Analyst tools within ArcScene):

1. Import the 3D sparse point layer, which represents all ice surface measurement locations as X,Y, Z.
2. Generate a concave hull polygon layer from the point layer. This may be used to quantify 2D area of the ice surface.
3. Interpolate a 3D raster layer from the 3D point layer using the Inverse Distance Weighted algorithm and a 0.05m pixel size.
4. Clip the 3D raster by the concave hull polygon so that the raster represents exclusively the area of the ice surface.
5. Optionally generate a contour polyline layer from the clipped 3D raster. Depending on the variance of the ice surface height, appropriate contour intervals should be chosen independently for each cave, and may need to change as time progresses.
6. Perform raster math, subtracting the clipped 3D raster from a previous "baseline" raster to produce a third 3D raster representing the net ice surface change.
7. Finally, calculate the volume in cubic meters of the ice surface change (using "Surface Volume" or "Polygon Volume" in ESRI's 3D analyst, or using the GRASS "r.volume" plugin in QGIS).

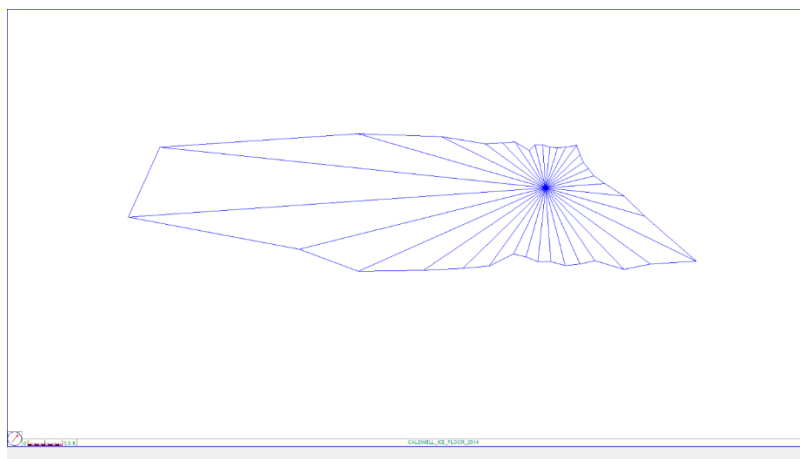


Figure 6-10. Example output from GIS processing of cave ice monitoring data for an ice perimeter with no surface contours.

6 Literature Cited

Dasher, G. 1994. On station: A complete handbook for surveying and mapping caves. National Speleological Society, Huntsville, Alabama.

7 Datasheets

Ice Monitoring Datasheet

Cave Name: _____ Date: _____

Observers: _____

Error tolerance for matching previous tripod locations: azimuth $\pm 2^\circ$; inclination $\pm 1^\circ$; distance ± 1 cm.

Ice Level

Measure distance from all ice level monitoring stations down to ice, and if present, to water.

From Station	Distance to water (m) to the nearest 0.00m	Distance to ice (m) ($^\circ$) to the nearest 0.1 $^\circ$

Photo Monitoring

Number of photos taken: _____

Number of photos missed: _____

Comments: _____

Transects

Set up tripod for area measurement. Select a transect azimuth based on previous years' data and current conditions. Measure distance and inclination to points 1 meter apart along the ice floor.

Transect Azimuth ($^\circ$) _____

Transect Azimuth ($^\circ$) _____

Distance (m) to the nearest 0.00m	Inclination ($^\circ$) to the nearest 0.1 $^\circ$	Distance (cm) down to ice edge	Distance (cm) back to ice edge

Distance (m) to the nearest 0.00m	Inclination ($^\circ$) to the nearest 0.1 $^\circ$	Distance (cm) down to ice edge	Distance (cm) back to ice edge

Ice Area

Measure distance, azimuth, and inclination from the tripod to all visible ice level stations (pins).

✓	To Station	Distance (m)	Azimuth ($^\circ$)	Inclination ($^\circ$)

Start Time: _____ End Time: _____ Starting Azimuth: _____

Point	Azimuth	Distance (m) to the nearest 0.00m	Inclination (°) to the nearest 0.1°	Distance (cm) down to ice edge (when rock blocks direct path to ice edge)	Distance (cm) back to ice edge (when overhanging rock blocks direct path to ice edge)
1					
2					
3					
4					
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Comments: