



Permafrost Monitoring Protocol for the Arctic Network

Standard Operating Procedures

Natural Resource Report NPS/ARCN/NRR—2017/1397



ON THE COVER

Aerial view of a retrogressive thaw slump in the Noatak Valley, Alaska (upper photograph) and a closer view of ground ice exposed in the main scarp of the slump (lower photograph).

NPS photos by Ken Hill, 21 June 2010.

Permafrost Monitoring Protocol for the Arctic Network

Standard Operating Procedures

Natural Resource Report NPS/ARC/NRR—2017/1397

David K. Swanson
National Park Service
4175 Geist Road
Fairbanks, Alaska 99709

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Introduction

Permafrost underlies most of the Arctic Inventory and Monitoring Network (ARCN) and has been selected as a monitoring vital sign. Significant thaw of permafrost is considered likely with future climate change, and this thaw would have important ecological consequences, such as drainage of lakes, creation of new ponds, soil erosion, slumping, siltation of streams and lakes, release of greenhouse gasses, and changes in soil wetness and nutrient supplies leading to vegetation changes. Long-term monitoring of permafrost will focus on monitoring of ground temperatures and monitoring of permafrost-related landforms. Ground temperatures will be monitored at climate monitoring stations; this monitoring will help us understand the vulnerability of permafrost to thaw. Landform monitoring will track some of the outward effects of changes in permafrost on ecosystems. Landforms will be monitored with remote sensing in 3 different projects: 1) comprehensive mapping of bare-soil features produced by thaw of permafrost (active-layer detachment failures and retrogressive thaw slumps) on high-resolution satellite imagery; 2) intensive monitoring of selected retrogressive thaw slumps by three-dimensional modeling using small-format aerial photography; and 3) monitoring of ice-wedge degradation and other thermokarst features using high-resolution imagery.

This report contains the Standard Operating Procedures for the Arctic Network permafrost monitoring protocol.

A. Standard Operating Procedures for Ground Temperature Monitoring

These Standard Operating Procedures are used to monitor ground temperatures, as described in Section 2 of the protocol narrative document (Swanson 2017) and Swanson (2016).

Table A1. Deliverables schedule for ground temperature monitoring.

Identifier	Deliverable	Format	Schedule	Responsibility	Description
A1	Climate monitoring site description	Records in database tables	Once	PI	Soil, site, and vegetation descriptions
A2	Ground temperature data	Records in Aquarius database	Annually	ARCN Physical Scientist	Hourly soil temperature data, managed together with other climate monitoring data.
A3	Summary report	Document file (pdf)	Every 5 years (beginning 2016)	PI	Either an NPS Natural Resource Report or peer-reviewed journal article

Standard Operating Procedure (SOP) # 1: Installation Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Temperature Probe Installation

Campbell Scientific model 107 temperature probes are attached to an ARCN climate station's Campbell Scientific meteorological station and data logger. For details on the installations and programming of these stations, refer to Sousanes (2006) and unpublished revisions.

B. Site characterization

Choose a spot with similar landform and vegetation to where the sensors were placed and complete a soil description according to accepted U.S. Department of Agriculture methods (Soil Survey Staff 1993; Schoeneberger et al. 2002). This will typically be within 10 m of the station tripod, but positioned so as not to disturb the ground over the sensors. Use the field form and symbols from SOP#4 of Appendix B of Swanson and Neitlich (2016; the ARCN vegetation monitoring protocol).

In addition to a soil description, record the site characteristics as in SOP#4 of Appendix B of Swanson and Neitlich (2016). The data elements we record at the climate stations are listed below, all defined as in Swanson and Neitlich.

component
position
slope_shape_vertical
slope_shape_horizontal
vegetation1
vegetation2
vegetation1%
vegetation2%
aspect
gradient
frozen
water_table
wet
hole_depth
parent_material1
parent_material2
parent_material3

Record "aspect" (slope aspect) as one of 8 cardinal directions, since degree-level precision is not possible on these nearly level sites. Since there is no plot defined, vegetation observations are made for an area approximately 10-m radial distance from the tripod, the community that best represents the site characteristics of the instruments and the soil pit. For this area, estimate cover by species of all vascular plants and the selected list of nonvascular species, genera and unknowns from SOP#5 of Swanson and Neitlich (2016). Cover classes are <1% (recorded as 0.1 to allow to go into a numeric database field), 1%, 3%, 5%, and thereafter 5% increments from 5% to 100%.

Standard Operating Procedure (SOP) # 2: Data Retrieval and Management

Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Campbell Scientific weather stations

Data will be transmitted and stored with the atmospheric climate data as specified in “Climate monitoring protocol for the Central Alaska Network” (Sousanes 2006 and unpublished revisions). Equipment will be maintained according to that protocol also. Note especially any evidence for disturbance or displacement of the soil temperature sensors.

B. Soil and site descriptions

Enter soil descriptions and site data into the database, currently stored as an Access database "ClimateSiteDescriptions.accdb" on the network drive under the Permafrost Vital Sign. The raw soil description data from the field forms goes in the table "soil_horizon". Using the field data, write narrative soil descriptions for each horizon in the table "soil_horizon_narratives" using the format in Soil Survey Division Staff (1993). The site variables are entered into the table "climate_stations". Plant species cover is entered in narrative form in the field "species_cover".

Standard Operating Procedure (SOP) # 3: Data analysis and summary

Version 1.0 (Feb 2017)

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Version No.	Revision Date	Author	Changes Made	Reason for Change

At no more than 5-year intervals, download the data from the server where they are stored as described below and compute these summaries. The following data analysis and summary were used in Swanson (2016).

A. The Aquarius database

A1. Login. ARCN climate data, including soil temperatures, are stored in an Aquarius database (<http://aquaticinformatics.com>), which is the software chosen by the U.S. Geological Survey to store its water data. The Aquarius database is managed for the NPS by the Water Resources Division in Ft. Collins, Colorado. Contact the data management specialist at the Natural Resource Stewardship and Science Directorate, Water Resources Division in Ft. Collins to obtain a login onto the database and the latest database user guides. You will receive a remote desktop connection file called "AQAssistant.rdp" and guidance on the latest training information available for the database. Double click on "AQAssistant.rdp" to automatically log into the server "inp2300fcvgett1.nps.doi.net". Enter your full NPS password (not your smart card PIN) and the login process will install a hidden icon on the lower right corner of your screen. Expand the hidden icons by clicking on the arrow and right-click the Aquarius icon to obtain a drop-down menu for accessing Aquarius; choose "Launch Springboard" for most data visualization purposes. You will get a login window for "Server: localhost", press OK and in the following login window enter your NPS login name (minus the "@nps.gov") and full password again. Our data are available in the NPS folder "Arctic Network".

A2. Data inspection. Aquarius Springboard provides a convenient tool for visual inspection of the data. Select a station and hit the arrow icon "Go to Data Sets". From the Data Sets screen, select one or more soil sensors. And then hit the graph icon "Quick View". Time series plots will appear. Inspect the data for unusual jumps in temperature or long periods with no change. Use the various magnifying glass icons to zoom into portion of the curve for closer inspection. Note the "zero curtain" portions of the plot, which are visible in the spring and fall at most sensors (except those with insufficient water). As the temperature crosses 0° C, it usually pauses for a few days while both liquid water and ice are present in the soil. The zero curtain temperature should be between -1° and 0° C and similar between years.

A3. Daily and monthly means. Daily and monthly means for each soil sensor and the air temperature sensor are computed and stored in the Aquarius database as "Time Series Statistical Derived". The daily mean computations are set to automatically filter for days with more than 80% of hourly data present (other days are listed as "no data") and the monthly mean computations are also set to filter for months with 80% or more days with data present (and other months are listed as "no data").

B. Aquarius batch data download

Data are conveniently downloaded using the Aquarius web service and REST protocol. The following Python script automates this process for all of the ARCN climate stations. Edit the "outpath" variable near the top to match the directory where you want the output files to go. The next line "locations=[" is the list of location names in the Aquarius database for all ARCN stations.

The script requests your login and password (same as above for AQAssistant.rdp). It loops through all of the locations and downloads all of the sensors that start with "TS." or "TA." (soil and air temperature) and also contain the string "month_mean".

The script uses the "pandas" Python library (<http://pandas.pydata.org/>) to crosstab the data from a 3-column date-sensor-value format to multiple columns with dates as the first column and sensors as the other column headings and values beneath. It thus requires you to have installed the "pandas" library. The script saves the data in both the crosstab and original 3-column "list" formats. The output files are in csv (comma-delimited) format, one for each station.

```
#Script to download monthly data summaries from Aquarius and crosstab into
one row per month
#DS 10/2015

outpath =
'C:\\Users\\DKSwanson\\Documents\\ClimateMonitoring\\Aquarius\\MonthlyXtab
s\\'

# locations to request
locations=['BELA_Devil Mtn','BELA_Ella Creek','BELA_Midnight
Mtn','BELA_Serpentine','CAKR_Mt Noak','CAKR_Tahinichok','GAAR_Chimney
Lake','GAAR_Killik Pass','GAAR_Pamichtuk Lake','GAAR_Ram
Creek','KOVA_Salmon River','NOAT_Asik','NOAT_Howard
Pass','NOAT_Imelyak','NOAT_Kaluich','NOAT_Kugururok','NOAT_Sisiak','HDOA',
'KAVA','KLLA','KTZA','NRUA']

# import libraries
from urllib2 import urlopen, quote #used to submit REST Internet request
for data
from pandas import pivot, DataFrame #used to create crosstab from data
list
import getpass #used to hide typing when password is entered

# AQUARIUS Server and login info
server="inp2300fcvgett1.nps.doi.net"
# base url for API calls
baseurl="http://"+server+"/AQUARIUS/Publish/AquariusPublishRestService.svc
/"
user=raw_input('login>')
```

```

password=getpass.getpass("password>")

token=urlopen(baseurl+'GetAuthToken?user='+user+'&encPwd='+quote(password)
).read()

# subroutines to assemble api request statements
def args(a): #routine to format arguments for an api request
    s="?"
    for i in xrange(0,len(a)-1,2): s+=str(a[i])+"="+quote(str(a[i+1]))+"&"
    return s[0:len(s)-1]

def apirequest(sub,*a): #routine to compose an api request string
    return baseurl+sub+args(list(a)+['token',token])

ds_names_all=[] #create empty list to append dataset names to
d=[] #create empty list to append data into

#Main program loop
for loca in locations:
    print loca #to track progress
    #create list of monthly summaries for location
    request=apirequest("GetDataSetsList","locID",loca)
    datasets=urlopen(request)
    for dsitem in datasets.readlines()[1:]: #skip header line
        if ',' in dsitem: #avoid empty lines with no commas at end
            ds_name=dsitem.split(',')[1] #dataset name is 2nd item in list
            ds_names_all.extend([ds_name]) #in brackets so that extend appends
the string as a whole
            ds_monthly = [s for s in ds_names_all if (("TS." in s or "TA." in
s) and "month_mean" in s)] #subset of air or soil T monthly datasets

    #download data for the monthly data sets
    for dataset in ds_monthly:
        request=apirequest("GetTimeSeriesData","dataID",dataset)
        data=urlopen(request)
        for dataitem in data.readlines()[5:]: #skip 5 header lines
            if ',' in dataitem: #need to avoid empty lines at end
                realdata=dataitem.split(',')[1:3] #time and actual data are items
1 and 2 in list
                realdata.append(dataset) #add name of dataset to line of data
                d.extend([[realdata[0][0:7], realdata[1], realdata[2]]]) #append
only the year-month (chrs 0:7); not sure why need double brackets

        df = DataFrame(d) #convert data from list to pandas data frame
        d_pivot=df.pivot(index=0, columns=2, values=1) #make crosstab with
dates as rows and columns as data sets
        d_pivot.to_csv(outpath+loca+'_xtab.csv', index_label='month') #save
pivot result to csv file
        df.to_csv(outpath+loca+'_list.csv') #save list result to csv file

    ds_names_all=[] #empty list of dataset names
    d=[] #empty results string for next location

```

C. Summary statistics

Open the data downloaded in the previous step in a spreadsheet and compute running 12-month means for each soil sensor and the air temperature; assign the running mean to the first month of the

12-month period. Plot these means vs. month to examine trends. Compute the sum of positive values (thaw degree-days) for each thaw season for the air temperature sensor.

Test for the significance of trends using the Seasonal Kendall test, as implemented with R package `rkt` (Marchetto 2015). To run this test, format the monthly data downloaded in the previous step for one sensor into 3 columns, named "decyr" (the decimal year, computed as year + (month - 1)/12), "mon" (the month as a number from 1 to 12), and "temp" (the mean temperature for that month). Start R, edit the input path and input filename to match yours, and run these two statements:

```
inpath <- "O:/Monitoring/Vital Signs/Permafrost/Results/SoilTemperature/"
infile <- "Rinput.txt"
```

Now paste together the path and filename, and read the table into a data frame called "dataset". Note that this `read.table` command is expecting comma-delimited data. Use the command `'sep="\t"'` instead of `'sep=","'` if you have tab-delimited data.

```
inpathfile <- paste0(inpath, infile)
dataset <- read.table(inpathfile, header=TRUE, sep=",", na.strings="NA",
dec=".", strip.white=TRUE)
```

Load the `rkt` library (you must have installed it previously)

```
library(rkt)
```

If you would like to run just part of the time series set the start and end dates, and run the subset command to put the result into data frame "testdata":

```
startdate <- 1977
enddate <- 2016

testdata <- subset(dataset, dataset$decyr>=startdate &
dataset$decyr<=enddate)
```

If you want to use the whole data set either set the limits outside of the range of the data, or simply copy all the data into "testdata":

```
testdata <- dataset
```

Now run the seasonal Kendall test. This test will compare like months across all of the years and then merge the results from all of the months to produce an adjusted probability of monotonic trend. The arguments to `rkt` here are the date of the sample (in decimal years), the mean temperature, the grouping variable (months), and a switch to correct for correlation between months:

```
rkt(testdata$decyr, testdata$temp, testdata$mon, correct = T)
```

In the results, note the "corrected" p-value (corrected for inter-block correlation). The direction of change is given by "Tau" or the slope value.

D. Other climate data

To gain a longer-term perspective, similar computations can be made on air temperature data from the weather stations near ARCN: Bettles, Kotzebue, and Nome. These data are available from the Applied Climate Information System (ACIS), at <http://xmacis.rcc-acis.org/>. Select "Single-Station", "Monthly Summarized Data", output "CSV-LIST", Variable "Avg temp", and station selection ID 500761 (Bettles), 505076 (Kotzebue), or 506496 (Nome). From these data you can compute running means and Seasonal Kendall tests as described above.

E. Deep borehole data

The UAF deep borehole temperature data are currently stored as Microsoft Excel spreadsheets on the University of Alaska Fairbanks Geophysical Institute's website (http://permafrost.gi.alaska.edu/sites_list/). There are multiple spreadsheets listed with different dates. They are cumulative, so you can download the latest one for a site and get all of the data to date. See Table 2 for a list of the sites most relevant to ARCN. Plot the time series of a common depth for all the holes. Because these measurements are made once per season, the depth chosen should be below the depth of annual fluctuation (about 20 m; Osterkamp 2005). Swanson (2016) found 26 m to be a useful depth available for all locations. Test for trends with linear regression or the Mann-Kendall test. For the latter, use the `rkt` package (described above) but in this case the test is simpler because there is just one number per year and no seasonal adjustment is made. For data where variable x is the year and y is the temperature, the command is:

```
library(rkt)
rkt(x, y)
```

Report the Mann-Kendall p-value and Theil-Sen's slope.

F. Active-layer data

The CALM active-layer data are available from <https://www2.gwu.edu/~calm/data/data-links.html>. At the time of this writing the data were available as a Microsoft Excel spreadsheet containing all years and all locations in the northern hemisphere. Numbers in the table represent means of the maximum thaw depths of multiple measurements across the grid each year (see the "Method" column). Select the locations relevant to ARCN (Table 3), and plot thaw depth versus year. Test for trends using linear regression or the Mann-Kendall test. The syntax is the same as in part E above, with variable x in this case being the thaw depth in cm.

Section A Literature Cited

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B. Standard Operating Procedures for Mapping of Thermal Erosion Features

These Standard Operating Procedures are used to map thermal erosion features, as described in Section 3 of the protocol narrative document (Swanson 2017) and Swanson (2010, 2012, 2014).

Table B1. Deliverables schedule for mapping of thermal erosion features

Identifier	Deliverable	Format	Schedule	Responsibility	Description
B1	Imagery for thermal erosion analysis	Raster GIS data	Every 10 years starting 2008	PI	High-resolution satellite imagery (resolution 1 m or finer) covering the retrogressive thaw slump monitoring area (Fig. 7)
B2	Thermal erosion features points table	Records in database	6 months after receipt of imagery	PI	Feature ID, feature type, and coordinates used to map the erosion features. Contains multiple points for discontinuous features
B3	Thermal erosion centroid points table	Records in database	6 months after receipt of imagery	PI	Feature ID, feature type, and coordinates for erosion feature polygon centroids
B4	Polygon GIS layer of thermal erosion features	Shapefile	6 months after receipt of imagery	PI	Erosion feature GIS polygons
B5	Summary report	Document file (pdf)	9 months after receipt of imagery	PI	Either an NPS Natural Resource Report or peer-reviewed journal article

Standard Operating Procedure (SOP) # 1: Mapping of Bare Soil Polygons Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Overview

The basic steps in the process are

1. Compute Normalized Difference Vegetation Index (NDVI) of high-resolution imagery
2. Smooth the NDVI image with a median filter.

3. Recode pixels as vegetated or non-vegetated based on a chosen threshold value for the NDVI score.
4. Convert the unvegetated pixel areas to polygons.

See Fig. 9 for a visual representation of this process. NDVI computation and smoothing is time-consuming for large images. Thus it is efficient to set up a batch of multiple images to run through the first two steps. Detailed directions for the automated process follow below

B. Compute NDVI and smooth

Compute NDVI using ArcGIS Spatial Analyst map algebra, and smooth the resulting image with a median filter using Spatial Analyst Focal Statistics. The Python script below completes these tasks in a batch process using an input list of file names called input.csv. This file consists of a list of input image file names, followed by a comma and your chosen names for the output NDVI rasters. For example:

```
20060819_053_00600000.tif,053_0600
20060830_559_01400000.tif,559_1400
20060830_560_01300001.tif,560_1301
20060830_561_01200000.tif,561_1200
20060830_561_01200001.tif,561_1201
```

Save this as “infile.csv”. Note that there are no spaces after the comma. There are no file extensions on the output file names, the script automatically adds a *.img extension (ERDAS imagine file format). The Python script is listed below.

```
# -----
# IKONOS_NDVIbatch.py
# Created on: Mon Jan 04 2010 by D.K. Swanson
# Revised for ArcGIS10 3 Feb 2011
# Orthorectifies the IKONOS tiff images then computes NDVI
# -----
# User edits here
inpath = "X:\\IKONOS\\NWAK\\BGRN\\po_519436\\"
outpath =
"C:\\GIS\\GISdataLocalBackup\\IKONOS_NDVI\\GAARresults\\NDVIimages\\"
intxtfile =
"C:\\GIS\\GISdataLocalBackup\\IKONOS_NDVI\\GAARresults\\infile.csv"
# End of user edit section-----

# Import system modules
import sys, string, os, arcpy
from arcpy import env
from arcpy.sa import *
env.workspace = outpath

# Check out the ArcGIS Spatial Analyst extension license
arcpy.CheckOutExtension("spatial")

# Read input and output file names from infile.txt
infilelist = open(intxtfile, 'r')
for linex in infilelist:
    line = linex[0:-1]    #delete the newline character
```

```

        items = line.split(',') #split the line into a list of items
        infile = items[0]      #assign variables sequentially to items in
list
        outfile = items[1]

        print infile #to track progress

        # Assemble input file name for orthorectification
        inraster = Raster(inpath + infile)
        # Assemble output file name for ortho; can't delete or overwrite this
while script is open so must make it unique
        ortho = "ortho" + outfile
        # Process: orthorectify the NDVI raster
        arcpy.CreateOrthoCorrectedRasterDataset_management(inraster, ortho,
"DEM", "#", "X:\DEM\NED_30mRS\aknedm_rs30", "#", "#", "GEOID")

        # Assemble file names for NDVI calculations
        red = Raster(outpath + ortho + "c3")
        NIR = Raster(outpath + ortho + "c4")
        outputNDVIimage = outfile + "NDVI.img"

        # Process: Map Algebra to compute NDVI, Focal Statistics to median
smooth
        tempimage1 = Con(NIR, 1000 * (NIR - red) / (NIR + red), "", "VALUE >
0") #assign no data to pixels with all zeros on image margins
        tempimage2 = FocalStatistics(tempimage1, NbrCircle(3, "CELL"),
"MEDIAN", "DATA")
        tempimage2.save(outputNDVIimage)

infilelist.close()

```

Copy this code in the Python IDLE editor and save as a file named IKONOS_NDVI.py or a similar name (the extension must be .py). (In the future, to modify this file, right-click on the .py file and choose “Edit with IDLE”.) Note the top several lines have user inputs that you must edit: the input path, the output path, and the input text file path and name. If you paste in a path name, be sure to make the folder separators double back slashes “\” or fore slashes “/”. This script orthorectifies the IKONOS image using the DEM identified in the command “arcpy.CreateOrthoCorrectedRasterDataset_management”; this path and filename may need to be changed in the future. Note that the script multiplies NDVI times 1000, so that it can be stored to 3 decimal places in an integer raster.

C. Set the break values for differentiating bare soil vs. vegetation on the NDVI image

Note: this step is usually done interactively with SOP 3 below, “Creating a point layer of erosion features”; determine and check the breakpoint as you locate erosion features.

Display the smoothed NDVI image produced by the previous step in ArcMap. Adjust the threshold value separating vegetated and unvegetated areas as follows. Double click on the smoothed NDVI layer in the ArcMap table of contents to open layer properties and choose “symbology”. Change the selection in the “Show:” box to “Classified” and change the number of classes under “Classification” to 3. Next hit “Classify” and change the first two breakpoint values to -50 and 0 (or similar) by typing into the “Break Values” box (leave the 3rd value in the box at the default maximum value for

the layer). The reason you want three classes is to view two different possible breakpoints at once (in this case, -50 and 0). Click OK and then OK again on the “Layer Properties” window. The resulting display should display in black or gray the areas with exposed bare soil, plus miscellaneous other low NDVI areas such as rock outcrops. Verify that the bare soil areas are mapped properly by one or the other of the two break points and adjust the break points if needed. The NDVI of wet bare soil, sparse vegetation over shallow ponded water, and water is also low, so some confusion here is unavoidable.

D. Convert the NDVI image to a polygon shapefile

Use the “Con” and “RasterToPolygon” geoprocessing tools in ArcGIS, with the break values from the previous step, to separate bare soil from vegetated areas. The Python script below runs these tools

```
# -----
# IKONOS_NDVIpols.py
# Created on: Mon Jan 04 2010 by D.K. Swanson, modified 7 Feb 2011 for
# ARCGIS10
# Thresholds the NDVI image at a chosen value, reclassifies to 0 or 1
# Then converts to polygons
# -----
# User edits here
inpath =
"C:\GIS\GISdataLocalBackup\IKONOS_NDVI\NOATresults\NDVIimages\"
inimage = "175_0800" #this is the name of the raster, minus the .img
extension
outpath =
"C:\GIS\GISdataLocalBackup\IKONOS_NDVI\NOATresults\TmpPolys\"
NDVIBrkPt = "-100"

# End user edits-----

# Import system modules
import sys, string, os, arcpy
from arcpy.sa import *

# Check out the ArcGIS Spatial Analyst extension license
arcpy.CheckOutExtension("spatial")

InputNDVIimage = inpath + inimage + ".img"
outshape = outpath + inimage + ".shp"
condition = "VALUE < " + NDVIBrkPt

# Process: Con... to reclassify NDVI image as 0 (bare soil, etc) or 1
(vegetation)
tempimage1 = Con(InputNDVIimage, 0, 1, condition)

# Process: RasterToPolygon
arcpy.RasterToPolygon_conversion(tempimage1, outshape, "SIMPLIFY",
"VALUE")
```

Copy this code in the Python IDLE editor and save as a file named “IKONOS_NDVIpols.py” or similar (the extension must be .py). Edit the top four lines to have the proper in- and out paths, the image name, and NDVI breakpoint.

Standard Operating Procedure (SOP) # 2: Create a point layer of thermal erosion features

Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background

The purpose of this SOP is to identify erosion features using high-resolution imagery and digitize them into a point layer. This point layer will be used in a subsequent SOP to differentiate the thermal erosion features of interest (active-layer detachment failures, ALDs, and retrogressive thaw slumps, RTSs) from other bare soil areas mapped by automated process in SOP #1. Certain attributes of the erosion features are also stored in the point layer. This information can be readily transferred to any map of thaw feature outlines (i.e., a polygon shapefile) using a spatial join. The point layer will maintain the identifying information about the feature even if the polygon boundaries are changed by new mapping. The spatial join can be performed in such a way that polygons will receive the label from a point that is near but not inside it, to deal with minor registration problems or situations where the original point location has re-vegetated but other parts of the feature are still bare.

Sources of erosion feature locations may include field GPS measurements and features identified on imagery. Features may be identified prior to the creation of bare-soil polygons described above, but a comprehensive visual scan should also be made of the high-resolution imagery overlaid with the bare-soil polygons generated above and point features identified to date. Imagery with a resolution of 1 m or smaller is needed for reliable identification of features with minimum dimensions of 5 to 10 m, such as narrow active layer detachments.

B. Create a sampling grid

To make comprehensive visual scan of an image, overlay a square grid with 4 km by 4 km cells on the image and systematically visit each cell at a viewing scale of 1:20,000. Small erosion features are not quite visible at this scale, so you must zoom to 1:10,000 scale or larger to any parts of the cell that could plausibly have erosion features. Zoom to 1:5000 or 1:6000 for final visual identification. A topographic map, DEM, or stereo viewing can be used to determine the topographic setting of the bare areas, which aids in their identification. To create the square grid with 4 by 4 km cells in ArcMap, run the Create Fishnet geoprocessing tool (under Data Management Tools, Feature Class). Use the following inputs:

Output feature class – a temporary shapefile

Skip past the “Left, Right, Top, Bottom” boxes

Fishnet Origin Coordinate – enter the x and y of an arbitrary point on your map,

Y-axis coordinate – for the x coordinate, ditto the x coordinate of the origin; for the y coordinate, add a round figure such as 100 m to your y coordinate of the origin. This will orient the grid north-south east-west.

Cell Size Width – 4000 (note: this assumes you are working in Alaska Albers or other projection in meters)

Cell Size Height – 4000

Number of Rows – 3

Number of Columns – 10

Uncheck the “Create Labels” box

Accept the default Geometry Type (POLYLINE)

Next, add this shapefile to your map, select it in the table of contents, right-click and select “Convert Features to Graphic”. Now you can remove the shapefile from your project and delete it. Use the drawing toolbar arrow to select the new graphic grid and under the “Drawing” dropdown menus choose “Group” to group all the lines into one graphic. Now use the drawing toolbar arrow and the drawing toolbar’s “rotate” tool to move and rotate the grid so that it aligns properly with your image. When you move to a new image, simply drag this grid to the new position and leave it in place until you have finished the inventory of that image.

C. Identification of erosion features

The mapping method used here will capture all areas with low NDVI, including bare soil, bare rock, rock rubble, cloud shadows, terrain shadow, water, and sparsely vegetated areas with shallow ponded water. Generally, only a small portion of the area with low NDVI will actually be features of interest. We are interested specifically in bare areas that owe their existence to rapid erosion caused by thaw of permafrost. These are mainly active-layer detachments (ALD) and retrogressive thaw slumps (RTS; for definitions see Van Everdingen 2005).

C1. Active-layer detachments produce strips of bare soil 10 to 30 m wide and up to hundreds of meters long on slopes; they stand in sharp contrast to adjacent, densely vegetated areas (Figs. 5 and 9). ALD are distinguished from other bare soil areas by their shape, the presence of a deformed soil-vegetation mat at their downhill end, and orientation vertically up and down a slope. Features readily confused with ALD include: 1) elongate snow beds (which lack the deformed vegetation-soil mat, are often oriented across the slope, and often have a snow patch in summer imagery); 2) elongated eroded areas along small streams (which also lack the deformed vegetation mat, typically have pointed as opposed to blunt ends, and have a stream entering and exiting from their upper and lower ends); and 3) elongate patches of scree or rubble, which again lack the deformed vegetation-soil mat and typically occur in a pattern related to bedrock outcrops.

C2. The features of RTS that distinguish them from other unvegetated areas include: 1) generally equant shape with an escarpment along part of the perimeter; 2) location on slopes with fine-grained

geologic materials (as opposed to terrain with coarse rubble or exposed bedrock); and 3) evidence for transport of significant sediment from the RTS, in the form of an evacuation channel or debris fan (Figs. 6 and 11; Lacelle et al. 2010). Many RTS occur along a river or lakeshore bluff that provided the initial exposure of ice to thaw. RTS are sometimes difficult to differentiate from barren slopes of river bluffs. In the absence of thaw slumping, a bare area on the river bluff is expected to be a simple slope near angle of repose (or steeper in consolidated material) that ends abruptly at the floodplain where material is removed by fluvial erosion. RTS are identified in these settings if the escarpment has retreated back, usually developing a curved form with a steep scarp and gently sloping floor.

C3. Areas inundated by water after thermokarst subsidence, or subsided areas where the vegetation layer persists should not be mapped. We generally will not map the narrow bands of bare soil found on the collapsing banks of lakes in thermokarst depressions, unless they expand away from the bank in the form of an RTS. At this time we will also not map narrow gulleys that form along ice-wedge networks along lakes and streams unless they expand to expose large areas of bare soil.

D. Create a point shapefile

Create a point shapefile named after the NPS unit, e.g., “BELAerosionPts”. This will be referred to as the erosion feature point layer. Open the attribute table and add the following fields (click on Options, Add Field; make each field text with a length of 10):

ErsnFtID – an identifier string consisting of the NPS unit code followed by a sequential four-digit number, e.g., BELA0012. This identifier refers to a single genetically linked geomorphic feature, i.e., a single active-layer detachment. If an erosion feature has several separate patches of bare soil, create a point for each so that the multiple polygons will all be identified, but give them all the same ErsnFtID. ErsnFtID allows us to answer questions like “How many ALDs are in NOAT?”, which is usually more useful than a count of the number of individual bare soil patches; there may be many small patches in a re-vegetating erosion feature.

ErsnFtType – the genetic type of thermokarst or slope failure. Choices are: ALD – active layer detachment, RTS – retrogressive thaw slump, OTH – other (large collapsed pingo, gulley, etc).

SUBSECCODE – the Ecological Subsection code. This code is used to compute summaries and is obtained from the Ecological Subsections map of the park unit. SUBSECCODE may be added by spatial join, but this method produces a new file and requires additional steps to avoid adding all the data from the subsections map. Probably the easiest way to add only the code is to select a group of points that fall within a subsection by their spatial location, then manually type or paste in the codes (if there are few records) or use the field calculator. To use the field calculator, right-click on the field, choose Field Calculator, and a dialog box appears. Type the subsection code into the lower box in quotes (the expression “SUBSECCODE =” should already be present), check “Calculate selected records only” (the default), and hit OK.

Note that for convenience in data entry we are placing redundant information in the erosion feature point layer: “ErsnFtType” and “SUBSECCODE” are actually unique for each “ErsnFtID” but not for every point. This situation will be corrected at the end of the mapping process below.

E. Digitize the point features

Add the “Editor” toolbar if needed and start editing the erosion point feature shapefile. Keep the attribute table open and add the attributes for the new records as they appear. It is helpful to display the NDVI image created in the previous SOP when digitizing erosion features. Click the NDVI image on to draw your attention to potential erosion features and off to allow viewing of the features. After you find erosion features, adjust the display to determine the optimal NDVI cutpoint as described in SOP #1, step D.

Standard Operating Procedure (SOP) # 3: Creating a Polygon Layer of Thermal Erosion Features

Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Join erosion feature points to polygons

The low-NDVI polygons created in SOP 1 are spatially joined to the point layer identifying thermal erosion features (created in SOP 2); then polygons not flagged by the points are deleted. The following Python code performs these steps, and also adds to the attribute table a field that contains the image source of each polygon. Note the user input section at the start of this script that must be edited. Be sure to edit both the input shapefile ("175_0800.shp" below) and the image source ("20080809_175_0080000.tif" below).

```
# -----
# IKONOS_NDVIpolyPtJoin.py
# Created on: Th Feb 04 2010 by D.K. Swanson, modified 7 Jan 2010 for
# ARCGIS 10
# Script to join erosion feature points to polygons
# and label the polygons with their image source
# -----
# User inputs below
pathpolysin =
"C:\GIS\GISdataLocalBackup\IKONOS_NDVI\NOATresults\TmpPolys\"
inpolysfile = "175_0800.shp"
pathpolysout =
"C:\GIS\GISdataLocalBackup\IKONOS_NDVI\NOATresults\JoinPolys\"
pointsfile = "C:\GIS\GISdata\Erosion\NOATresults\NOATERosionPts.shp"
imagesource = "20080809_175_0080000.tif"
joinradius = "20" #the distance a polygon can be from a point and still
be included
# End of User input section-----

# Import system modules
import sys, string, os, arcpy
from arcpy.sa import *

# Check out the ArcGIS Spatial Analyst extension license
arcpy.CheckOutExtension("spatial")

# Spatial join of erosion points with NVDI polygons
infile2 = inpolysfile[:-4] #trim off the file extension .shp
```

```

target = pathpolysin + infile2 + ".shp" #the polygon shapefile we're
joining point data to
outfile = pathpolysout + infile2 + "SpatialJoin.shp"
arcpy.SpatialJoin_analysis(target, pointsfile, outfile, "JOIN_ONE_TO_ONE",
"KEEP_COMMON", "#", "CLOSEST", joinradius)

# Create a feature layer and select high-NDVI polygons to be deleted
layer = outfile + "lyr" #have to make unique layer names because it won't
overwrite
arcpy.MakeFeatureLayer_management(outfile, layer) #to select polygons
from a shapefile, you have to 1st create a layer
query = '"GRIDCODE" = 1' #select the polygons with high NDVI to delete;
field name in quotes for shapefile!
arcpy.SelectLayerByAttribute_management(layer, "NEW_SELECTION", query)
# Delete selected polygons
arcpy.DeleteFeatures_management(layer)

# Add new field to contain the source of the polygon
arcpy.AddField_management(outfile, "ErsnFtSrc", "TEXT", "#", "#", 50)
# Populate source field
arcpy.CalculateField_management(outfile, "ErsnFtSrc", 'imagesource',
"PYTHON")

# Add another new field to contain the area of the polygon
arcpy.AddField_management (outfile, "AreaSqM", "DOUBLE")

# Delete various unneeded fields
arcpy.DeleteField_management (outfile, "Join_Count; GRIDCODE; Id_1;
xAlb83; yAlb83")

```

B. Edit the polygons

B1. Check your polygons against the original image to make sure they cover the features properly. The most common problem is an ALD or RTS that is contiguous with other low NDVI areas (e.g., a river floodplain or water body) that must be trimmed off. Occasionally, one must delete unwanted polygons (which may be accomplished by simply selecting the unwanted polygons and hitting the delete key), append an adjacent area to the polygon, or create a new polygon. The most complex problem occurs when two or more erosion features border a low-NDVI area, such as a river or lake. In this case a large amalgamated polygon will be present with the attributes of just one of the points, so both the polygons and attributes must be fixed. These various operations are described below.

B2. Create a new polygon. Start the editor, choose the correct layer to edit, open the “Create Features” window if it isn’t open already (using the Editor dropdown), click on the polygon construction tool, draw the new polygon, double-click to finish. Remember that you will have to populate the attributes of a new polygon.

B3. Trim unwanted portions of a polygon. 1. Add the editor toolbar and start an edit session if you haven’t already. 2. Select the offending polygon. 3. Click on the “Cut Polygons Tool” on the editor

toolbar. 4. Draw a line that splits the polygon, making sure it snaps to the polygon edge. 5. Double-click to end. 6. Select the unwanted part of the polygon and delete.

B4. Enlarge a polygon to include an adjacent area. Proceed as above for cutting polygons, except use the “Reshape Feature Tool” in the editing toolbar; click around the area you want to add, then finish by double-clicking. If the area you add is complex, ArcMap may delete your original polygon. If so, undo the operation and try again with a simpler addition. To add multiple parts to the same polygon, you will have to save after each part is added. Small adjustments to a polygon can be made using the Edit Vertices tool.

B5. Split multiple erosion features from one large polygon that includes an unwanted area. There are several ways to accomplish this. The easiest way is to edit the original polygon layer produced from the NDVI image prior to the join of the polygons with the points (SOP #1, part E). Select and split the amalgamated polygon (as described in part B3 above) so that each point occurs in a separate polygon (no need to delete any polygons here as the join step will take care of most of them). Then repeat the spatial join step in part A above. Unfortunately, the shapefile from SOP #1E is usually very large and bugs may be encountered during the edit. If this happens you can edit the much smaller polygon shapefile obtained from the spatial join (after step A above) and manually fix the attributes. Split the amalgamated polygon so that each point occurs in its proper small polygon, delete the unwanted portion, and then edit the attributes of each new sub-polygon so that each matches the point that it encompasses. This becomes tedious if there are many new polygons; advanced ArcMap users may want to edit the *SpatialJoin shapefile, delete all of the attribute columns (except for FID, shape, ID, and GRIDCODE), then re-run the spatial join to the points to attribute the polygons automatically.

B6. Remove duplicate polygons. Where images overlap there will usually be two versions of the map of each erosion feature. The two versions may be viewed by displaying both the new *SpatialJoin shapefile and the master polygon layer described below in part C. The differences between the versions are due to: 1) registration error (adjacent images do not coincide exactly); 2) image spectral properties and analysis threshold values (i.e., one version will usually map more erosion area than the other); and 3) changes on the ground between dates (formation of new erosion features, enlargement of a feature, or re-vegetation). In the present study we are mainly estimating the total number and area of erosion features; when differences in size and location of the polygons between images for a given feature is minimal, simply treat them as duplicates and delete one of the versions. Where differences are more substantial, choose the one that appears to be of better quality.

C. Merge to master polygon layer

Join the erosion polygon layers for the individual images to a master layer using the Merge (Data Management, General) geoprocessing tool. (Note: when running the tool, be sure that nothing is selected or you will only get the selected polygons in the output.) “Merge” creates a new file, so name them sequentially (NOATerosionPolys3.shp, then *4.shp, etc., as you add new areas.***D. Check for duplicates, add area attribute, file cleanup***

D1. Check for and remove duplicate polygons. In spite of step B6 above, there may be erosion features that have been mapped more than once in areas where images overlap. The easiest way to

identify the duplicate polygons is to query the attribute table of the master polygon layer in a database.

In Microsoft Access, import the *.dbf file from the shapefile into a temporary database. To be safe, copy this file and save it under a new name with *.dbf extension (less than 8 characters so that Access will accept it). Open Access and create a temporary database. Choose “External Data”, and under “Import” choose “More”, “Dbase File” . and navigate to your file, then import into the database.

Run a select query grouping by “ErsnFtID” and “ErsnFtSrc”. In Access, select “Create”, then “Query Design”, and close the “Show Table” dialog box. In the upper left-hand corner of the screen, select “SQL View” and copy the following code:

```
SELECT ErsnFtID, ErsnFtSrc  
FROM tmpNOAT  
GROUP BY ErsnFtID, ErsnFtSrc;
```

This query will work on a dbf file imported as “tmpNOAT”; edit the “FROM” statement to match your table name.

Next, search the results of this query for duplicated polygons that have the same “ErsnFtID” but different “ErsnFtSrc” (i.e., the same feature has polygons digitized off different images). This can be done using a summary query on the results of the above select query that counts the “ErsnFtSrc” field for features that have two different images listed. If that select query was named “Query1” the SQL code is:

```
SELECT Query1.ErsnFtID, Count(Query1.ErsnFtSrc) AS CountOfErsnFtSrc  
FROM Query1  
GROUP BY Query1.ErsnFtID  
ORDER BY Count(Query1.ErsnFtSrc) DESC;
```

Now compare the output of this query to the master polygon layer and examine the duplicate polygons, deleting the extras as described in step B6 above. Some of the features with two image sources in fact straddle an image boundary and thus the two images do not represent an error.

Cross-check the points and polygons files for irregularities. Compare temporary copies of the shapefile dbf files from the polygons and point shapefiles in the database by running a join query between the two files on “ErsnFtID”. There may be a few points without a matching polygon (if the mapping routine failed to find a low-NDVI area near the point, but all polygons should have a corresponding point.

D2. Add the polygon area attribute. After an area of interest has been mapped, add polygon area to the attribute table of the erosion feature polygon layer. Right click on the polygon shapefile and select “Open Attribute Table”. Click on Options and select Add Field. Name it “AreaSqM”, change the type to “Double”, and press OK. Right click on the new field and select “Calculate Geometry”. Use the dialog box to compute the area of the polygons using the coordinate system of the data

source (which should be Alaska Albers) in units of square meters. Sort on the new area attribute and delete all sliver polygons with area of less than 2 m².

D3. File cleanup. Once all of polygons have been merged to the master data set, the intermediate files with “SpatialJoin” suffix, and the large files containing all of the bare soil polygons that the erosion polygons were derived from should be deleted. The NDVI images should be retained, as a substantial amount of computing time has been invested in them.

Standard Operating Procedure (SOP) # 4: Database Normalization

Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background

After the previous SOPs have been completed, there is redundant information in the erosion feature point and erosion feature polygon layers. Specifically, information associated with each ErsnFtID is duplicated for multiple points and polygons. The following steps will rectify this situation and prepare the data for import into a database. The basic steps are to collapse the erosion feature points attribute table to produce one record per ErsnFtID with data that is unique to each feature, then delete this information from the erosion feature point and polygons attribute tables. Henceforth, this information can be obtained using a one-to-many table join on field ErsnFtID. As a minor enhancement we will also calculate a centroid of the points that make up each erosion feature so that each ErsnFtID also has one x-y coordinate set that may be plotted or shared.

B. Add x and y coordinates to the erosion feature point attribute table

These directions assume your data are in Alaska Albers NAD83.

B1. Add the latitude and longitude to the attribute table. Open the erosion feature point attribute table. Click on Table Options (upper left icon) and select Add Field. Name the new field “lonDD83”, change the type to “Double”, and press OK. Right click on the new field and select “Calculate Geometry”. Fill the dialog box to compute “X Coordinate of Point” in the coordinate system of the data source (decimal degrees). Repeat for the y coordinate: click on “Options” and select “Add Field”, but name it “latDD83”, change the type to “Double”, and press “OK”. Repeat the above steps using “Calculate Geometry”, except this time in the dialog box select “Y coordinate of Point”.

C. Produce a normalized erosion feature ID table

This step produces a table with one record per erosion feature, containing the type, subsection, and coordinates for the feature. The coordinates are obtained by averaging the coordinates of multiple points for features with disjunct pieces.

C1. Import data table. Import the attribute table from the erosion feature point layer into a database. The dBase table of a shapefile may be imported directly into Microsoft Access. Copy the *.dbf file and rename the file with less than 8 characters before importing. Open Access, choose “External

Data', and under "Import" choose "More", "Dbase File". Navigate to your file and import into the database.

C2. Compute x-y centroid and eliminate redundant records. Create a "select" query that averages the latitude and longitude for all the fragments of a single feature, and groups by all other fields (which are identical for all fragments of a single feature). In Access, select "Create", then "Query Design", and close the "Show Table" dialog box. In the upper left-hand corner of the screen, select "SQL View" and copy the following code:

```
SELECT ErsnFtID, ErsnFtType, SUBSECCODE, Avg(lonDD83) AS AvgOflonDD83,  
Avg(latDD83) AS AvgOflatDD83  
FROM NOATpts  
GROUP BY ErsnFtID, ErsnFtType, SUBSECCODE;
```

This SQL code will process an attribute table named NOATpts; rename the "FROM" statement as needed to match your table.

C3. Delete unneeded fields. From the erosion feature polygon layer delete "TARGET_FID" and "ID". In both the erosion feature point and polygon layers, "SUBSECCODE" and "ErsnFtType" are redundant and can be obtained by table join on "ErsnFtID" from the table created in step C2. However, for convenience these fields may be left in the shapefiles.

Standard Operating Procedure (SOP) # 5: Repeat Mapping and Change Detection Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

This SOP documents the method used by Swanson (2012) to document change in area of erosion features using historical aerial photographs.

A. Acquire imagery

Photography available for all of ARCN is c. 1980 AHAP (Alaska High-Altitude Photography), available from the U.S. Geological Survey at <http://edcsns17.cr.usgs.gov/EarthExplorer/>. These data may be scanned at 14 microns, (approximately 1 m resolution) or 20 microns (approximately 1.5 m resolution). The effective resolution of AHAP imagery is somewhat coarser than 1 m. To date we have successfully mapped many RTSs on AHAP imagery but have failed to detect many ALDs. The latter is probably due to some combination of the coarser resolution of AHAP imagery and the actual rarity of ALDs at that time.

B. Map erosion features Scanned color-infrared aerial photographs may be analyzed for erosion features by essentially the same process as described in SOPs 1 through 4 for IKONOS imagery. Note: for photography, omit the orthorectification step from the NDVI computation script. The result will be polygons registered to the aerial photographs and all area measurements will be in units of pixels.

Accurate area measurements can be made on orthorectified aerial photographs. Orthorectification is expensive and labor-intensive, and currently rather inaccurate in ARCN because of our low-resolution digital elevation model (DEM). Until a better DEM becomes available, reasonably accurate area computations may be made using the approximate scale of unrectified aerial photographs, because the photos are from high elevation and the erosion features are on relatively flat surfaces.

C. Georeference the photography and adjust the photo scale The approximate scale of unrectified photographs is obtained by georeferencing the photographs to orthorectified IKONOS imagery using a first-order (affine) transformation. Add the Georeferencing toolbar to ArcMap and follow the directions provided in ArcMap help for georeferencing. Choose 1st Order Polynomial (Affine) as the transformation type, and when complete choose “Update Georeferencing” to save the results. There is no need to create a transformed raster dataset (the “Rectify” option). Polygon layers

created from the photos will be adjusted to meters based on the affine transformation. In ArcMap, right-click on the photo, choose “Properties”, “Source” and read the values under Cellsize (X,Y). Average these two numbers for an approximate overall scale, and multiply the result times any areas measured using polygons made in units of the raw image coordinates.

Section B Literature Cited

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C. Standard Operating Procedures for Three-Dimensional Photographic Monitoring of Selected Thermal Erosion Features

These Standard Operating Procedures are for 3D monitoring of selected thermal erosion features, as described in section 4 of the protocol narrative document (Swanson 2017). In 2017 ARCN converted from a protocol where oblique aerial photographs were processed into 3D models using Topcon Image Master software and ground-surveyed control points, to a protocol where oblique or vertical aerial photographs are processed into 3D models using Agisoft Photoscan software and the aerial camera GPS coordinates to obtain the spatial reference. SOPs #1 through #5 below document methods used for all pre-2017 work and the reports Swanson and Hill (2010) and Swanson (2012, 2013). As of 2017, SOP #2 (Survey Ground control) is unnecessary, and SOPs #4 and #5 have been replaced by SOP #6. Oblique aerial photographs (taken according to SOP #3) may still be used occasionally, but they are processed by SOP #6. Specifications for photos and digital elevations models taken under contract are given in SOP #7.

Table C1. Deliverables schedule for 3D modeling of thermal erosion features

Identifier	Deliverable	Format	Schedule	Responsibility	Description
C1	Imagery for 3D analysis	jpg or jpg and RAW format	Every 2 to 4 years; delivered within 60 days of photography date	Contractor under guidance of PI	High-resolution aerial photographs
C2	Camera coordinates	Table in text format	Simultaneous with imagery	Contractor under guidance of PI	Coordinates from accurate airborne GPS, if available
C3	Digital elevation models (DEMs) and orthoimagery	Raster	Within 6 months of receipt of imagery	PI or contractor	DEMs and orthoimages created from the aerial photographs
C4	Polygon GIS layer of thermal erosion features	Shapefile	Within 6 months of receipt of imagery	PI	GIS polygons outlining the extent of the thermal erosion features
C5	Processing report for each model	pdf	Upon completion of processing imagery for a slump and year	PI or contractor	Report of basic accuracy parameters of the 3D model
C6	Summary report	Document file (pdf)	Within 6 months of receipt of imagery	PI	Either an NPS Natural Resource Report or peer-reviewed journal article

Standard Operating Procedure (SOP) # 1: Preparation for Fieldwork

Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Choice of monitoring subjects

Three-dimensional photographic monitoring is an intensive effort that will be restricted to high-interest and high-impact features, primarily retrogressive thaw slumps. The criteria used to choose subjects for monitoring include:

- Size. Features should cover at least a hectare or have the potential to grow to such size.
- Activity. Features should be active, as indicated by unvegetated areas or recent growth in size. Monitoring may continue on features that become inactive after monitoring has begun.
- Impacts on other resources. Erosional features that cause sediment loading of water bodies are of special interest. Features that could destroy cultural sites are also important. Features that produce significant visual impacts for visitors may also be monitored.
- Cost. Subjects of marginal interest may be monitored if they are near to higher priority features and thus can be accessed at little additional cost.

B. Equipment (pre-2017 oblique photos and ground survey)

Digital SLR camera with fixed focal-length lens

Spare memory cards for camera

Surveyor's total station with tripod

Prism target and pole with topographic (blunt) shoe

Aerial mapping targets (tarps with large printed X)

Stakes for aerial mapping targets

Sighting compass

Mapping-grade GPS

2 short-range radios

Magnetic declination data (obtain for planned points and dates from:

<http://www.ngdc.noaa.gov/geomagmodels/struts/calcDeclination>

Tape measure (2-3 m length, for measuring height of instrument)

Spare batteries for total station, camera, radios, GPS

C. Equipment (oblique photos only, no ground survey)

Digital SLR camera with fixed focal-length lens

Spare memory cards and batteries for camera

Standard Operating Procedure (SOP) # 2: Surveying ground control

Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background

A ground survey is required to determine the scale and orientation of a 3D model. The absolute location or altitude of control points is not of concern, but we need accurate distances between control points and their elevations relative to one another. We obtain this by placing at least 5 targets before shooting photos and surveying their relative location to 10 cm accuracy or better with a laser device (total station). The absolute location of the survey points is determined to within about 1 m by differentially corrected GPS. Ground control does not need to be placed again in subsequent re-measurement years, provided that at least 3 (preferably 10-15) well distributed tie points can be located on the air photos from the survey visit and any unsurveyed visit.

B. Placement of temporary ground control points

Choose a spot with good visibility around the perimeter of the erosion feature for the total station. Select 5 other points that are visible from the station, on relatively smooth ground, and well distributed in space around the perimeter of the object under study in an approximately square arrangement. You may select points inside the erosion feature on flat areas of dried mud. Avoid placing all of the ground control points in a single line. Also, avoid spots where the helicopter prop-wash could tear or move the target during take-off or landing.

Mark each ground control point with a 1.5 by 1.5 m (60 by 60 inch) square fabric targets marked with an X, specially designed for this purpose. Stake at the corners to prevent the targets from being moved by the wind during the photo flight.

The aerial target for the total station point will be placed after the survey is complete and the tripod has been removed. The aerial targets for the other points are staked out before making the readings. When making readings, center the prism pole on the target and level the pole.

C. Operation of the total station

We will make measurement with the default setting of the instrument as X, Y, Z equal to 0, 0, 0. The true azimuth of the first station will be entered to align the coordinate system with true north. For additional information, see the Topcon total station manual (Topcon 2008).

C1. Setup. Set up the tripod and attach the total station; turn on power, level with the circular bubble. When properly leveled, the lower part of the readout will change from “<XY TILT OVER>” to “MEAS MODE S/A P1”.

C2. Measure instrument height. Mark the plumb point and measure the instrument height. Press the [MENU] key, then [F4] to scroll to the next set of choices, choose [F3](LASER PLUMMET), and then [F1] to turn on the laser plummet. Mark this spot with a stake (you will eventually center an aerial target over the stake). Measure the height of the instrument with a tape measure (from the plumb mark to the center of the telescope) and record it in your survey book. Turn off the laser plummet [F2] and hit [ESC] to leave the laser plummet mode.

C3. Enter the instrument height. Select the coordinate measurement mode on the instrument (button with 3 arrows). Select [F4](P1), then [F2](INSHT), then [F1](INPUT). Enter the height in m to 2 decimal places (cm). It should be near 1.5 m. [ESC] back to the coordinate measurement mode.

C4. GPS. Start the GPS running directly under the total station plumb point. If you are using a Trimble GPS, allow it to stabilize for at least 5 min and make a reading with at least 20 points. If you are using a recreational GPS, allow it to average for at least 10 min before taking a reading.

C5. Target height. Set the prism pole so that the target height is exactly 2 m. The target height on the instrument should be set at 2 m and left there. To check the target (reflector) height, select [F4] then [F1](R.HT). If it is not 2 m, select [F1](ENTER) and enter 2. You can change this during a survey to avoid obstacles in the line-of-sight, if prompted by a radio call from the target holder.

C6. Set up the target at the first point and enter the azimuth. The pole person moves to the first point to be surveyed, stakes the aerial target, sets the prism pole on the center, levels the pole, and aims the prism at the total station.

The instrument person determines the compass bearing from the total station to the first target with a sighting compass. Using an up-to-date magnetic declination guide for that location, correct the azimuth for declination by adding the declination to the azimuth. If the sum is over 360°, subtract 360° from the sum. Record both the corrected and uncorrected azimuths in your log book.

Aim the total station at the first point. Make a rough alignment using the sighting device on top. Then align exactly with the telescope and tighten the horizontal and vertical screws to hold it in place.

Select the angle mode with the [ANG] button, then [F3](HSET), then [F1](INPUT). Enter the corrected azimuth. Note that to enter fractions of a degree, use a decimal point followed by minutes. For example, to enter 5 ½ degrees, enter 5.30. *Be sure the instrument is aimed at the first point when you enter this azimuth.*

C7. Measure the points. Measure the coordinates of each point relative to the station and save the points in memory on the total station, with backup in your survey book. Make a sketch of the

thermokarst feature with the location of the control points, and label them with sequential numbers that match the point numbers in the data file.

After you have entered the azimuth for the first point, measure its location. Hit [MENU] then [F1](DATA COLLECT). Here you will see the file name used last (or a blank if there are none). You can hit [F4](ENTER) to accept this file, [F1](INPUT) a new file name, or [F2](LIST) to see existing files and choose another one. We will usually use one data file per day (name it after the date; use the down arrow key to see letters). Note: to INPUT a new file name you will edit the name of the current file. This will create a new empty file with the new name, without affecting the existing file. After entering or choosing the file name, hit [F3](FS/SS), then [F1](INPUT) to name the point (for point 1 only; after that it will number them sequentially), then [F3](MEAS) and then [F3](NEZ). *Be sure to enter a point name at the first point in a file.* The instrument will beep when the point has been located and advance to the next point. Note that you can change the target height on the point screen if needed. Aim the telescope at the next point and hit [F3](MEAS) , then [F3](NEZ) again to measure.

To review the points, hit [F2](SRCH) and then [F1](FIRST DATA) or [F2](LAST DATA) and scroll through your measurements with the up and down arrows. Write the coordinates of each point in your log book to be sure you have them. This will serve as the backup copy in the field. The coordinates are listed as N, E, Z of the target (meters north and east, and relative elevation) relative to the station.

Standard Operating Procedure (SOP) # 3: Shooting Oblique Aerial photographs

Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Camera setup

A1. Focal distance. Turn autofocus off (if the lens has autofocus) and set the focal distance at infinity and use a small piece of tape to hold it in place. Our photos are usually taken at a distance of 100 m or more.

A2. File format. Set the image file format to jpeg and choose the compression mode for highest possible quality.

A3. Exposure mode. Set the exposure mode to shutter speed priority with the shutter speed no slower than 1/500 second. Use an ISO setting of 200 but increase this to 400 if necessary to obtain enough light; or use the camera's automatic ISO feature.

B. Photograph layout

B1. Camera orientation. Shoot photos through an open window or door, at as steep a downward angle as possible without encountering the landing gear. Orient the camera with the long axis vertical ("portrait" setting; Fig. C1).

B2. Flight line. Fly past the feature of interest on a straight line, shooting successive photos perpendicular to the flight line. Avoid aiming forward or backward, or pivoting the helicopter while hovering, to capture the subject; to obtain stereo coverage and 3D of an object you must change your location, not just your view angle. Start and end the line well beyond the subject so that photos cover undisturbed ground beyond the slump, especially upslope. Stable areas with landmarks will be used as tie points between visits and provide documentation of undisturbed surface for tracking future slump growth.

B3. Photo overlap. Successive photos should overlap by at least 60% in the foreground (overlap in the background will be greater). All areas of interest must be covered by at least 2 photos, and alternate photos also should overlap a little. A useful technique is to choose at each shot a landmark near the bottom center of the frame when you shoot (at the bottom because nearby objects move out of view faster) and shoot again before the landmark leaves the field of view. A 60% foreground

overlap will allow a sufficient number of tie points between the photos to be located for construction of the stereo model. It will also ensure a proper photo base if you use a 35 mm or 50 mm lens with a full-frame sensor (the photo base is the distance between photos divided by the distance to the subject). With a smaller sensor, use a 35 or 24 mm lens.

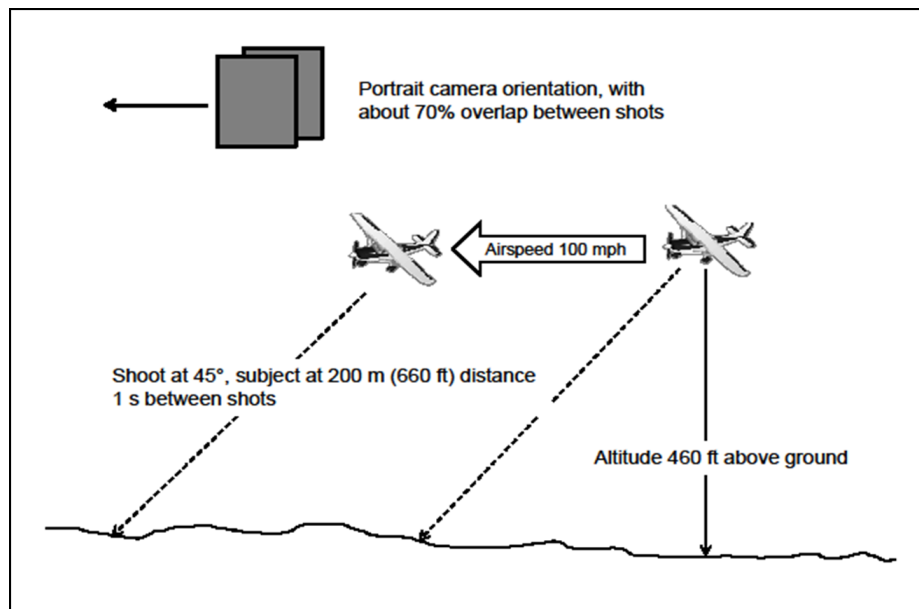


Figure C1. Setup for photography of permafrost erosion features.

B4. A typical pass. A typical pass has a flight speed of about 100 mi/hr (90 knots, 40 m/s), passing about 200 m (656 ft) away from the subject and 140 m (460 ft) above the ground (Fig. C1). With a 50 mm lens on a camera with a full-frame sensor (23.9 by 36 mm, e.g., Nikon D700), the narrow dimension of the field of view will be about 100 m wide and have 3.5 cm resolution. Shots taken 1 second apart will be separated by about 40 m, for a 60% overlap between frames. A similar result would be obtained using a camera with a standard digital sensor (e.g., 15.7 by 23.7 mm) and a 35 mm lens.

B5. Multiple passes. Most slumps require several passes with different flight lines and distances. If possible, shoot close enough to the subject to obtain about 5 cm per pixel resolution. For a NIKON D700 (which has a sensor of 23.9 by 36 mm and 4256 by 2832 pixels) with a 50 mm lens, a subject at 300 m will have about 5 cm resolution. For large features, more distant passes will be needed. Try to get one pass that is distant enough to cover all of the slump and adjacent areas of interest, such as re-vegetated slumps. For subjects more than 100 m wide, you will probably want to follow the distant, low-resolution pass with closer passes for greater detail. Remember that if you move closer, the photos will have to be shot with less time in between to maintain 60% overlap. Consider taking a close-up pass to see detail in the main scarp. A pass up each flank is useful for elongate subjects, but

vertical main scarp faces will sometimes not be visible so be sure to make a pass parallel to the main scarp also if it is steep.

Standard Operating Procedure (SOP) # 4: Creating 3D Model with Topcon Image Master Software
Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Calibrate the camera and lens

Shoot photos of the calibration sheet supplied by Topcon for Image Master software (Topcon 2005) and run the photos through the calibration software routine. See the Topcon Image Master Calibration software manual for instructions. Note that contrary to what the manual instructs, when shooting photos of the calibration sheet you will need to focus your camera to something less than infinity to obtain quality calibration photos.

B. Total station data file transfer

After returning from the field, transfer the data using the Topcon serial cable and “Topcon Link” software.

B1. Download Topcon Link software from
<http://www.topconpositioning.com/products/software/utilities/> and install

B2. Attach the Topcon serial cable to the total station and the computer.

B3. Start Topcon Link. Choose “File”, “Import from Device”. If this is the first download on this computer you will have to add the total station. Click on “Topcon Total Stations” and then on “Add New Station”. Give the total station a name that combines the model number and NPS unit. Choose the model number most like yours if there is no exact match (e.g., GTS-310 for GTS-235) and then OK.

B4. Click on “Topcon Total Stations” and then double-click on your station. A dummy file called “file1.txt” appears in the left-side window. In the right-side window, navigate to the folder on your computer where you want the data file to go (note: shortcuts may not work here; if so, navigate to your file the long way). In the left window, click on “file1.txt” and then hit the >> button. A dialog box appears (“Download file from Total Station”) with directions for operating the total station.

These differ slightly from the sequence you will actually see on the total station. Leave this dialog box open and go to the total station as described below.

B5. Turn on the total station. Select [MENU], [F3](MEMORY MANAGER), [F4](page down) twice and then [F1](DATA TRANSFER). Be sure [F2](RS-232C) is selected and hit [F4](ENTER). Select [F1](GTS FORMAT), then [F1](SEND DATA). Next choose [F1](MEAS. DATA) (which gives you all the data the instrument collect) and arrow to your file (or press [F2](LIST) to see a list of available files, then arrow to the file you want) and hit [F4](ENTER). On the “SEND MEAS. DATA” screen hit [F3](YES). A screen appears that says “SEND MEAS. DATA” at the top and “STOP” in the lower right corner. To trigger the transfer, go back to your computer screen and hit the “Start” button on the “Download file from Total Station” dialog box, which should still be open from the above step. “File1.txt” should appear in your target folder. Immediately rename it (in the Topcon “Import from Device” window) to “*Meas.txt” where “*” is a unique identifier (typically the date in YYYYMONDY format).

B6. The total station screen will return to the “SEND DATA” screen where you chose [F1](MEAS. DATA). If you have more files to download, select [F1](MEAS. DATA) and proceed as above. Note that each time a file is transferred is called “file1.txt” and must be renamed (use the original file name based on the date) to avoid overwriting previously downloaded data. Continue until all the files have been transferred.

B7. Convert the files to “csv” format. In Topcon Link, select “File”, “Open File”, and select one of the text files that you exported above and the coordinates will appear. Next choose File, Save As, choose Format name “Name,N,E,Z,Code – Coordinates (*.csv)”. This will match the coordinates as you wrote them in the field notebook, but note that they are actually ordered as Y,X,Z. Name the file using the date as before. Open the file in your spreadsheet software and add the date and the name of the site or feature to each record by referring to your field book and sketches. Then append them to the master list of control points. Note: if you forgot to name the points in the field, they will not show up in the “csv” file (but they are still saved in the raw text file of measurements). If this happens, copy the coordinates from your field book and check them against the text file. Each N, E, and Z are the 4th, 5th, and 6th numbers in each row of the text file.

B8. After all files have been downloaded from the instrument, converted to “csv” format, checked to make sure they match your field book, and backed up, the data files should be deleted from the instrument. On the instrument, hit [MENU], [F3](MEMORY MGR.) [F3](FILE MAINTAN.), arrow to the file as needed and hit [F3](DEL), [F4](YES). Note that for each date you will have to delete two files, a “/M*” file and a “/C*” file (the measurement and coordinate files, respectively).

B9. Merge the new points with the master control point file.

C. Trimble GPS data

C1. Data download. Upon return from the field, download the daily GPS data files from the GPS to the project folder on the O: drive. There should be one file from each day, labeled “RmmddyyA.SSF”, where mmddyy is the month-date-year.

C2. Differential correction. Perform a differential correction of the GPS data following the most recent instructions provided by the NPS GPS Coordination Program NPS Alaska Region office.

C3. Data export. Export the differentially corrected coordinates (from the *.cor files) to text files. Choose “Sample Generic Database Setup” as your export setup. This produces a comma-delimited text file. In the export dialog box, click on “Properties” and leave all at the defaults except for the Attributes. Here check “Receiver Type”, “Date Recorded”, “Time Recorded”, “Vertical Precision”, and “Horizontal Precision”. Then click “OK” in the “Properties” dialog box and “OK” again in the “Export” dialog box.

C4. Concatenate the export files. If you saved multiple GPS rover files, it is easiest to merge them before proceeding. The following DOS copy command can accomplish this easily. Type or copy text as follows into a text editor and save as “ConcatFiles.bat”:

```
Copy file1 + file2 + file3 + file4 slumpGPS.csv
```

List all the files as needed (be sure to include their extensions), separated by plus signs, with the destination file at the end.

C5. Add column headers. Open the concatenated export files in a text editor and paste the following first line of column headers:

```
"record", "GPScorDD84lon", "GPScorDD84lat", "hae", "easting", "northing", "GPScorZ", "descr", "GPStrmModel", "GPStrmDate", "GPStrmTime", "GPScorVertPrec", "GPScorHorzPrec"
```

Check the “descr” column to make sure it matches the slump name used in the coordinates file in part B above.

C6. Append. Append the resulting table to the master list of GPS coordinates.

D. ImageMaster Project Setup

D1. Create an Image Master Project. Before starting (before creating or loading any Image master Projects, be sure that under “Setup” the coordinate system setting in “Mathematical (XYZ:ENH)”. Create an Image Master project for each slump, named after its GIS ID number. Image Master will create a folder with this name, containing a project file (*.imj) and subfolders for each model. Add additional subfolders in the project folder named “ControlPoints” and “ExportFiles”.

D2. Create a model. Create a model for each “pass” (set of photos shot along a line), named by the year and consecutive letter. For example, the model for the first pass shot in year 2010 is named “Pass10A”. In Model mode, select “File”, “Model”, “New Model”. In Orientation mode, click on the

“xyz” icon to load the ground control points. Be sure that the station point is included (point zero, coordinates 0,0,0) by adjusting the number of header lines expected. Click on the camera icon and navigate to the folder where the photos are; open the folder and hit “Select” - you don’t need to select individual photos yet. A dialog box opens with thumbnails of the photos. Typically you will select all of the photos, though some peripheral shots may be omitted. Decline the option to copy all of the photos to the project folder. In the first blank called “Camera Name”, navigate to and select your camera calibration file. Click on the “Register” button to add the photos. If you need to remove an image, right-click on its thumbnail and select “Delete”. It will be deleted from the project, but the original file will not be deleted. Next define all of the stereo pairs. Work across your thumbnails from left-to-right along a flight line; click on the left member of the pair, then ctrl-click on the right member, then hit the “Add Stereo Pair” button (two rectangles), repeating until all pairs have been defined.

E. Photograph orientation

E1. Background. The locations of the cameras and photos in space is determined by bundle adjustment using common points (“pass points”) identified on adjacent photos.

E2. Define pass points between photos. In Orientation mode, double-click on the first stereo pair. Windows appear for each member of the pair, with the whole image on top and a zoomed window on the bottom, defined by a blue box on the upper image. Move the blue box by clicking on the upper image. To change its magnification, select the Zoom tool (the +- magnifying glass icon) and click on the lower half of the window: left click to zoom in and right click to zoom out. Find common landmarks on the two photos, zoom in, click on the “Measure Tie Point” tool, click on the landmark in both windows; green crosshairs will appear. Name the pass points as follows: pass A: a1, a2, a3, etc., pass B: b1, b2, b3, etc. Be sure to place pass points across the full extent of the area you wish to model, including surrounding undisturbed areas. Concentrate on the areas near the edge of one of the two stereo photos, and try to find points that will be visible on three adjacent photos. The minimum number of pass points needed to link a stereo pair is 6, but 8 to 10 is recommended. Rocks or bare soil areas can be located with more precision than shadows of shrubs or tussocks, but use the latter as needed in vegetated areas. Also, a pointed corner of a large shrub can be located more precisely than its middle. Toggle the zoom button on and off while leaving the “Measure Tie Point” dialog box open to automatically increment point numbers. Image Master will automatically advance to the next pass point number until you close the “Measure Tie Point” dialog box.

E3. Locate control points on the photos. For photos that had a ground survey, find each aerial marker; zoom in, click on the measure tie point icon (circle with crosshairs), click on the target center; in the dialog box that appears, name it the same as it is in the field notes and the control points file that was compiled in section B above.

E4. Bundle adjustment. When you have finished locating control and pass points on a pair of photos, calculate the orientation by hitting the calculator icon. A warning box comes up asking you to set a layer of control points. For the moment, choose “Continue computation without setup” and then OK. You will get an Orientation Results box that describes the outcome of your bundle adjustment.

Ideally the “Y-Parallax” and “Image Coordinate” error values will both be less than 1 pixel, but in practice they are often just over 1 and still produce good models. If errors are moderate (i.e., around 10 pixels), you probably either chose the wrong camera calibration model when you loaded the photos (fix this under “Orientation”, “Camera”, “Change camera”) or you have a point that is slightly mis-located on one photo. Problem points can be identified by examining the “Image Coordinates” tab in the “Orientations Results (Error)” box that appears after the bundle adjustment, or finding the same information in the “BundleResult.txt” file (scan down to the section that lists the results for the stereo pair with problems and note the points with the worst y-parallax, “y-prx”). Go back to ImageMaster and check the location of these points. If you find one that is mis-located, select it with the arrow tool, then right-click and choose “Re-measure”. Click again on the proper location for the point and enter.

If ImageMaster attempts a bundle adjustment and fails with very high image coordinate errors (100 pixels or more), you have probably misnamed a point, e.g., duplicated a pass point name in two locations. The tie point list (under “Orientation” in Orientation mode) is helpful for locating these. Look for points that are defined on multiple photos, especially non-adjacent photos. Rename mislabeled points by selecting them with the arrow icon, then right-click, rename.

Continue with orientation of the photos. Click on the next stereo pair and repeat the previous steps of pass point location and bundle adjustment. Be sure to locate all the previously defined points on the new photo, using the same names. As you define new points, be sure not to duplicate any names at new locations. If you forget the last point name you used, open “Orientation”, “Tie Point List” to view the points measured so far. Do the calculations after every stereo pair so that it will be easier to locate a mistake. This will also save your pass points to disk, which is useful because Image Master can crash suddenly.

F. Incorporating ground control (for passes with ground survey)

F1 Set up a control point file for the model. Open the master list of control points, to which your new points were added in section B above. Copy the points that belong to the specific slump and year that you are working on to a new file called “XXXXXXXXControlPtsYYYY.csv”, where X is the slump identifier (e.g., NOAT070) and Y is the year. Add a line at the top with POINT, N, E, and Z of 0, 0, 0, 0 to correspond to the total station point (which was also marked with an aerial target). Also, we will work in Image Master with columns of x, y, z, so you must exchange the N and E columns in your table (you want the x-axis to be east-west and the y-axis to be north-south). Save as csv (comma-delimited) and then return to Image Master and in Orientation mode open “Orientation”, “Orientation Settings”, “Control Points”, “Read File”. Navigate to the file, check to make sure you have defined the right number of header lines (to avoid missing the first line), and hit “Import”. Run the bundle adjustment again; you should get a result that is similar but slightly worse than the

uncontrolled model. If the bundle adjustment fails, check to make sure the control points are named properly.

G. Registration of unsurveyed models

G1. Background. Models created from photographs from different years are registered to one another using landmarks. Typically, one of the years will have ground survey points and the other will not, and the scale of the unsurveyed model is taken from the surveyed model. The process of transferring ground control from one set of photos to another is laborious, and thus we have developed two approaches, one that is quick and suitable for visual comparisons between years (“approximate 2-dimensional registration”), and a second that is time-consuming but accurately co-registers the two models so that they can be compared quantitatively in 3D (three-dimensional registration”). The same techniques can be used to transfer ground control to a model produced during a survey year from a pass with too few ground control points (i.e., less than 3 points). For example, a close-up pass of the main scarp provides interesting detail but may only cover 1 or 2 control points and ground control must be transferred from a larger model using landmarks.

G2. Approximate 2-dimensional registration. First, create a 3D model and orthophoto for the year with ground control as described in section H below.

Create an orthophoto from the unscaled model. To create an orthophotograph for the uncontrolled model, you will need to artificially define a nearly level plane to which the photograph is projected. Pick 3 of the pass points that you used to compute the bundle adjustment: one on the upper left side of the slump (defined as if you are facing the slump main scarp from the bottom), one on the upper right side of the slump, and one in the middle of the lower part. Open the BundleResult.txt file for the model and scroll down to the place that lists the computed coordinates for the pass points. This will look like:

[Calculated Coordinates]

Calculated Coordinates and Residuals

<i>PointName</i>	<i>X[m]</i>	<i>Y[m]</i>	<i>Z[m]</i>
<i>e1</i>	<i>2.9013</i>	<i>2.0530</i>	<i>-7.9263</i>
<i>e2</i>	<i>2.1413</i>	<i>0.0778</i>	<i>-5.0015</i>
<i>e3</i>	<i>1.7310</i>	<i>-1.0285</i>	<i>-3.3135</i>
<i>e4</i>	<i>4.7108</i>	<i>1.7314</i>	<i>-7.2716</i>
<i>etc.</i>			

Find the three points you chose and copy their coordinates into cells B3 through E5 of a spreadsheet with these formulas:

	A	B	C	D	E	F	G	H	I	J
1			Original Arbitrary Coordinates					Rotated Arbitrary Coordinates		
2		point	x	y	z		point	x	y	z
3	UpperLeft	e33	10.8328	1.1562	-4.8392		=B3	0	0	0
4	UpperRight	e40	9.9849	-1.465	-0.9832		=B4	0	=C8	0
5	Bottom	e20	6.9733	0.1108	-3.9048		=B5	= $(C9^2-H5^2)^{0.5}$	= $(C8^2+C9^2-C10^2)/(2*C8)$	0
6										
7			Interpoint Distances Original					Interpoint Distances rotated (check)		
8	UL_UR	a	= $((C3-C4)^2+(D3-D4)^2+(E3-E4)^2)^{0.5}$					= $((H3-H4)^2+(I3-I4)^2+(J3-J4)^2)^{0.5}$		
9	UL_B	b	= $((C3-C5)^2+(D3-D5)^2+(E3-E5)^2)^{0.5}$					= $((H3-H5)^2+(I3-I5)^2+(J3-J5)^2)^{0.5}$		
10	UR_B	c	= $((C4-C5)^2+(D4-D5)^2+(E4-E5)^2)^{0.5}$					= $((H4-H5)^2+(I4-I5)^2+(J4-J5)^2)^{0.5}$		

The points here are e33, e40, and e20 in yellow. In this case the results from the formulas (in yellow) are:

	A	B	C	D	E	F	G	H	I	J
1			Original Arbitrary Coordinates					Rotated Arbitrary Coordinates		
2		point	x	y	z		point	x	y	z
3	UpperLeft	e33	10.8328	1.1562	-4.8392		e33	0	0	0
4	UpperRight	e40	9.9849	-1.465	-0.9832		e40	0	4.7390252	0
5	Bottom	e20	6.9733	0.1108	-3.9048		e20	3.569966526	2.029049968	0
6										
7			Interpoint Distances Original					Interpoint Distances rotated (check)		
8	UL_UR		4.739025					4.7390252		
9	UL_B		4.106301					4.106300619		
10	UR_B		4.482034					4.482033775		

What the spreadsheet does is compute the inter-point distances using the Pythagorean theorem (in cells C8 through C10). It then computes new coordinates for the three points in cells H3 through J5, with G3 through G5 providing labels. These new coordinates all have a z-value of zero, the upper left-hand point has x-y coordinates of 0, 0, and the original inter-point distances are maintained (cells H8 through H10 confirm this). Next copy the values from G2 through J5 into a new spreadsheet (remember to paste values; a general paste will generate errors as it tries to paste formulas), save as csv format (comma-delimited) named for the model as before except flag it as “arbitrary points” rather than true ground control points (e.g., NOAT076arbtPts.csv), then import this into Image master as a control point file (Orientation, Orientation Settings, Control Points, Read File, navigate to the file). Run the bundle adjustment again (you should get identical results as before). If your bundle

adjustment fails, try switching your upper-right and upper left points in the spreadsheet above and run through the process again.

Next, create a 3D model as described in section H below. Since your model has arbitrary scale, the usual 2 m grid spacing will not be appropriate. In the Auto Surface Measurement dialog box where the Mesh Interval is set, try a value that is about $1/50^{\text{th}}$ of the interpoint distances in the spreadsheet above, or in this case about 0.1; adjust to a smaller number if more detail is needed. Finally, generate an orthophoto from your arbitrarily oriented model by the usual process (step H2 below). Note that this orthophoto is geometrically correct but projected onto a plane that is sloping at the approximate rate of the slump, in contrast to a true orthophoto that is projected onto a vertical plane. However, this approximate orthophoto will be adequate for the 2-dimensional measurements described below. Sometimes the model will appear very dark in Image Master; this is because it appears upside-down. Use View Rotate Bottom View to flip it over before generating the orthophoto. Accept the default orthophoto resolution unless this appears too coarse.

Register the unscaled model onto a scaled model. Import orthophotos from the models with and without ground control into ArcMap and adjust the uncontrolled model using the Georeferencing toolbar. Place the uncontrolled photo on top in the ArcMap table of contents. Open the georeferencing toolbar (“Customize”, “Toolbars”, “Georeferencing”) and choose the uncontrolled photo as the “Layer” to georeference. Click on the X-X icon to mark common points between the two photos. First click on the landmark on the upper (uncontrolled) photo, then shut it off on the display and find the same landmark on the lower photo. ArcMap will progressively rotate and rescale the photo as you identify more points and the process should get easier. You may need to delete some of the early, less accurate tie points as registration progresses. To assess the error of individual points, open the “Link Table” (square icon on the georeferencing toolbar), click through the tie points (they will highlight on your screen), and delete any with high errors. Note that on the Link Table you have a choice of Transformation. The default is 1st Order Polynomial (Affine), which should be adequate in this case. Stop when the two orthophotos match to sub-meter accuracy, open the Link Table, save the tie point list, then click on the Georeferencing dropdown and choose “Update Georeferencing”. The change in area between years and distance the main scarp migrated can now be calculated from the georeferenced orthophotos as described below in section I. You cannot plot useful cross-sections (you don’t know what is level) or compute volumes for the uncontrolled model.

G3. Three-Dimensional Registration. Three-dimensional registration requires these steps: 1) find common points on photographs from the two years (or two passes in the same year to register a close-up model without good control to a wider model with good control), 2) calculate the x-y-z coordinates for these points on the model with ground control, and 3) use these coordinates as control for the photos from the unsurveyed year.

Create Image Master Models and run orientation/bundle adjustments for the year with ground control, as described in sections D, E, and F above. For the year without ground control, it is easiest to create the model after locating the tie points to the year with ground control.

Locating tie points between years: overview. The object is to find 10 to 15 tie points between the two years that are scattered around the slump and, if possible, in stable areas within it (typically in the lower part). If the photo passes from the two years have very similar perspectives, the tie points can be created in Image Master. This in principle is the faster option, but we have found it to be very difficult in Image Master to identify common landmarks on photos taken from different perspectives in different years. It is not possible in Image Master to rotate and rescale one photograph to match the other in order to reliably find common landmarks. We have found the georeferencing tools in ArcMap to be very helpful for identifying tie points between photos. ArcMap georeferencing automatically rotates, rescales, and warps one of the photos to match the other as you identify tie points, greatly easing the process of locating the points. ArcMap georeferencing also allows you to export the resulting coordinates, which can then be brought into Image Master.

Define tie points in ArcMap. Select a pair of photos from the two years that covers the same general area of the slump. Add both to an ArcMap project. Choose the photo that provides the least distorted view of the slump (i.e., closer and more vertical) and place it below the other photo on the ArcMap table of contents; the upper photo will then be altered to match it on the display.

The pass points from the existing model for the year with ground control can be imported into ArcMap. Where possible we will use these landmarks as tie points, because they have already been located on all the photos from the surveyed year. To import the control points, find the *.imc file for the photo from the year with ground control, and open it in a text editor. Skip the first 3 lines of the file (header information) and copy the lines of data below (you should recognize your point names, and the next two numbers are x and y coordinates) into a new text file (skipping the final zero at the end). Use find/replace to change the field delimiters from multiple spaces to single commas. Add field names “point”, “xcoord”, and “ycoord” to the top line. Add a negative sign to all of the y coordinates. Add the table to the ArcMap project you just created. Right-click on the table and choose “Display XY Data” to create a layer with the points. Right-click this new layer and select “Label Features” to display the labels of the pass points

Open the georeferencing toolbar (“Customize”, “Toolbars”, “Georeferencing”) and choose the upper photo as the “Layer” to georeference. Click on the X-X icon to mark common points between the two photos. For photos with very different perspectives this will be difficult at first and you will probably need to make some approximate tie points to get started. First click on the landmark on the upper photo (the “Source” photo in ArcMap), then shut it off on the display and find the same landmark on the lower photo (the “Map” photo in Arc Map). ArcMap will progressively rotate and rescale the photo as you identify more points and the process should get easier. You may need to delete some of the early, less accurate tie points as registration progresses. To do this, open the “Link Table” (square icon on the georeferencing toolbar) and click through the tie points (they will highlight on your screen), and delete any with high errors. Note that on the Link Table you have a choice of Transformation. The default is 1st Order Polynomial (Affine), which is adequate in many cases. For very different perspectives you will get a better result from the Spline transformation, but this is only available after 10 or more tie points have been identified. Continue until you have several points scattered around the two photos that you are confident represent the same landmarks. Where

possible, use the existing pass points from the surveyed photos (the control points should snap to them when you get near).

With the Link Table open, note any points that you don't want to import into Image Master and delete them or record their numbers temporarily. On the link table, choose "Save" to save the points to a text file in the "Control Points" folder of the Image Master project. Name the file after the two photos, with the top photo ("X Source" and "Y Source" in the table) first in the name and the lower photo ("X Map" and "Y Map") second; for example, "7729_8915tiePts.txt" for photos 7729 and 8915. *Be sure you have none of the points selected when you save* (or it will save only the selected point).

Open the text file of link points that you just saved in a spreadsheet or text editor. It will look something like this:

408.145101	-1556.218695	457.090434	-663.144871
683.569569	-2323.879109	946.455558	-1778.956584
2373.658850	-2299.409093	2846.655439	-2661.662500
3329.895235	-412.238958	3965.357604	-1464.211409

The first two columns are x and y coordinates on the photo (in pixel units) for the top ("Source") photo (7729 in this case) and the 3rd and 4th columns are the x and y coordinates for the bottom ("Map") photo (8915 in this case). The points are listed sequentially, so you can delete any that you listed above and don't want to import. Copy the points into another spreadsheet for reformatting. Sequentially name these tie points t1, t2, t3, etc., reformat, and label them as follows:

Photo	TiePt	X	Y
7729	t1	408.145101	-1556.218695
7729	t2	683.569569	-2323.879109
7729	t3	2373.65885	-2299.409093
7729	t4	3329.895235	-412.238958
8915	t1	457.090434	-663.144871
8915	t2	946.455558	-1778.956584
8915	t3	2846.655439	-2661.6625
8915	t4	3965.357604	-1464.211409

Make a temporary list of which tie points correspond to existing pass points.

Open another pair of photos and repeat (be sure to change the layer that you are georeferencing). Note that for subsequent pairs of photos we will continue sequentially with new tie point names, do *not* start over again with t1 on each photo. Check which of the original pass points you have already located and don't repeat them, continue to note the pass points as you use them. Continue until you have 10 to 15 points scattered fairly evenly around the periphery of the slump and, if possible, in stable areas inside (usually in the lower part).

If you need to reload a tie point list and add more tie points after closing it, you can expect problems in ArcMap 10 due to saved georeferencing information. To work around these problems, move the saved georeferencing information for the photo (the world file *.jgw and auxiliary file *.aux) into a folder where ArcMap will not be able to find it (e.g. create a new folder called "hide"), delete the

photo from your ArcMap project, and then re-add it. Choose the photo you just added in the georeferencing dropdown and open the link table by clicking on the icon. From the link table dialog box, open the link table that you saved before (click on the “open folder” icon) and the photo you just added should appear with the links and transformation that you developed previously.

Import the tie points into Image Master. Unfortunately, at this time Image Master will not import text files of tie points, so we have to carefully format the coordinates and copy them into the files where Image Master stores points, the “*.imc” files in the model folders. Open one of these “*.imc” files and you will see:

<i>C:\Documents and Settings\..etc.\DSC_7729.jpg</i>	the photo path and file name_
<i>4256 2832</i>	the image dimensions in pixels
<i>8</i>	the count of points
<i>b1 240.5000000000 2005.0000000000</i>	The point name, x, y coordinates
<i>b2 296.7500000000 182.7500000000</i>	
<i>b3 1493.0000000000 23.0000000000</i>	
<i>b4 3312.5000000000 293.0000000000</i>	
<i>b5 2405.0000000000 669.5000000000</i>	
<i>b6 1191.7500000000 1202.7500000000</i>	
<i>b7 974.2500000000 701.7500000000</i>	
<i>b8 560.7500000000 767.0000000000</i>	<i>etc.</i>
<i>0</i>	End-of-file marker

We need to insert our points into the point list with proper formatting and update the count of points in line 3. Formatting requires padding the numbers to make 10 characters between the decimal points. Also the ArcMap y-coordinates (negative) need to be made positive. The easiest way to accomplish this is with a set of spreadsheet entries that rounds the measurements (sub-pixel accuracy is not needed), computes the number of blank spaces needed, and creates a string:

	A	B	C	D	E	F
1	Photo	TiePt	X	Y	padPt	roundx
2	7729	t1	408.1451	-1556.22	=REPT(" ",10-LEN(F2))	=ROUND(C2,0)

Cells A2 through D2 are the original data. E2 computes spaces needed after the point name and F rounds the x-coordinate.

G	H	I
padx	roundy	photo
=REPT(" ",10-LEN(H2))	=-ROUND(D2,0)	=A2

Continuing on the same line, cell G2 computes the spaces needed after the x coordinate, H2 rounds the y-coordinate and changes it to a positive number, and I2 repeats the photo name for ease of viewing.

J

```
string  
=B2&E2&F2&" .0000000000 "&G2&H2&" .0000000000 "
```

Continuing on the same line, cell J2 assembles the line of text that will go into the *.imc file for the photo listed in cell I2. If these formulas are dittoed down the table of tie points created in the previous step, column J will contain the formatted data. Copy the contents of column J out into a text editor, which for photo 7729 are:

t1	408.0000000000	1556.0000000000
t2	684.0000000000	2324.0000000000
t3	2374.0000000000	2299.0000000000
t4	3330.0000000000	412.0000000000

Using the text editor, paste these into the “*.imc” file for this photo (“DSC_7729.imc” in this case), and add the proper number to the count of points on line 3 of the file ($8 + 4 = 12$ in this case). Now when you open up this photo in Orientation mode in Image Master, the tie points should show up along with the pass points you defined previously.

Locate the tie points on stereophotos. In order to make use of a tie point, it must be located on multiple stereo photos within the same model and then used in a bundle adjustment. In Image Master, work through all of the photos from each model and locate each tie point in every photo possible, running bundle adjustments as you go to spot mistakes. On the surveyed model, any new tie points that match existing pass points don’t need to be located.

Use the tie points to create a ground control point file. After the tie points have been located in all the photos in both models (the one with and without ground control) and bundle adjustments run, open the “BundleResult.txt” file for the model with ground control and scan down to the section called “Calculated Coordinates and Residuals”. Copy these to a spreadsheet, sort by PointName, and delete the residual columns (DX, DY, and DZ). Rename the old pass points that you have adopted as tie points with the t# that you used (check the temporary list you created above), sort again by PointName, and delete all except the tie points (t1, t2, t3, ...). These have coordinates in meters that will become the scale for the model without ground control. Save these points as *.csv (comma-delimited) format with a file name based on the slump, pass names, and “tiePts.csv”, e.g., “NOAT070_10Ato11A tiePts.csv”. Now you can use these as control points as described above in step F, in the same fashion as ground survey points: open the unscaled model, in Orientation mode choose “Orientation”, “Orientation Settings”, “Control Points”, “Read File”, navigate to the file, “OK”. Now run a bundle adjustment and continue on with generating a 3D model as described in section H below.

H. Generation of 3D models

H1. Create a TIN (triangular interpolated network). ImageMaster will only calculate topography inside a polygon bounded by control points with known x, y, and z. Thus, models calculated from our ground control points alone will usually omit part of our area of interest. Fortunately, we can use the

calculated coordinates of our pass points from the bundle adjustment as control points and compute a model out to the limits of the pass points. First, rename the current bundle adjustment file “BundleResult.txt” to BundleResult1.txt” to prevent it from being overwritten. Then, open the file in a text editor, scroll down to the section that gives the calculated coordinates of all the pass points. Copy the calculated coordinates from the bundle adjustment output file to a spreadsheet (it is tab-delimited, so you should be able to paste it directly), delete any blank columns and the residuals (DX, DY, and DZ), then save as csv comma delimited). In Image Master, Orientation mode, “Orientation Settings”, “Control Points”, select this file as the “Layer of Control Points”. Run a new bundle adjustment; the results will be nearly identical to the original adjustment. Go into Stereo mode and double-click on one of the stereopairs. Then run “Auto Surface Measurement (Batch Processing)” (the icon is 3 blue squares split into triangles). The recommended mesh interval is 2 m; accept the default median filtering and texture mapping by combining multiple images. Wider point spacing (5 m) may be desired to reduce computation time for large models. Name the TIN after the pass, e.g., “SURFACE-Pass10C”. Note: if any of your control points are outside of the area covered by the photos (e.g., in a close-up pass as described in the previous section), the surface generation may fail. If this happens, create a new control point file without the extra points, and run the orientation calculation again, and then generate your surface.

After the TIN has been created, you can rotate and zoom it to inspect the result (note that you have to choose the model tab to view it rather than the stereopair). Check for problem areas. You can toggle the texture (air photo overlay) on and off on the Objects tab in the lower left of your screen. When the texture is off, you can switch between shaded relief and the TIN using the “Rendering” button (square with 4 triangles in shades of gray).

H2. Generate an orthophoto. Note that Image Master will create an orthophoto that mimics the perspective of your current view. To create a standard vertical orthophoto, in Model mode choose “View”, “Rotate”, “Top View”. Next, check the layer that contains your TIN and select the photos you want to include (typically all of the photos in the Image List). Click on “Data”, “Ortho-Image”, “Create”. In the resulting dialog box, name the orthophoto after the pass, set the Ground Resolution for 0.2 m/pixel (for models scaled in real meters; for unscaled models made by the 2D process above accept the default), and check the “Color Adjustment” box; it will prompt you to select one of the photos to be the basis for adjustment (choose one of the middle ones). After the orthoimage has been created, export it using “File”, “Export”, “Ortho-Image”, save into the Export folder in your model folder. Note that the orthoimage will come with a world file that allows it to be draped over the TIN in other software (e.g., ArcMap).

ImageMaster occasionally fails to create an orthoimage. Problems may be due to bad vertices in your TIN. See the next section “Editing TINs” to remove problem vertices so you have a smooth TIN. Also a model without ground control will occasionally appear inverted (the model will be very dark in Model view) and must be turned over using Model, View, Rotate, Bottom view, before an orthophoto can be made.

H3. Editing TINs in Image Master. You may edit bad vertices in a TIN. Look at the TIN with the photo texture on it and without (by toggling “Data”, “TIN”, “Rendering”; note the button/icon to

make this faster). Look for unexpected pyramids or holes on the TIN or places where the photo is highly distorted (note: pits are easiest to see by looking at the bottom of the TIN.) Edges of the TIN and vertical or overhanging areas are often problems. Don't worry about minor problems as they will not significantly affect calculations. In Model mode, click on the arrow tool and choose "TIN Vertex" as the data type. Click on the bad vertex and one you would like to match. Then choose "Data", "TIN", "Make Elevations Even". The dialog box will give you the range of selected vertices. Type in the value of the "good" vertex and hit "OK" to assign that elevation to both. You may have to de-select the previous vertices when you move to a new spot ("Edit", "Select None"). Odd vertices on the margins may simply be deleted using the delete key after selecting them, or by using "Data", "TIN", "Cut". The latter method is probably safer due to potential topology problems.

H4. Merging TINs. Sometimes you will need to merge 2 TINs to cover your whole area of interest. The following process will merge TINs that have a common set of control points that allows for an accurate join.

First, open the two models that you wish to merge, and export their TINs into the "Export" folder; export as "tin" (ImageMaster tin format that includes textures).

Next, create a new model named after the passes like "Pass10CDmerge" and import the multiple TINs into it ("File", "Import", "Shape File").

Select the area from each TIN that you want to include in a merged model. Search each TIN with the texture on for areas that show distortion, especially near steep slopes such as the main scarp. Display one TIN by unchecking the other TIN layer(s). Choose the Select Polygonal Area tool (in the Selection toolbar) to select the part of each TIN that you want to delete. When the Selection dialog box comes up, specify data type "TIN Vertex". Left-click around the area to delete, right-click to complete the polygon, and then hit the delete key. It is OK to leave some overlap as it will be averaged in the merge operation.

Select the TINs to merge using the arrow tool; this time choose TIN as the data type to select. Then run Data, TIN, Merge. Set the averaging resolution to the approximate pixel size of your data, typically around 0.2 m, Set the reference plane of the TIN to X-Y Plane. After the merge, check for any vertex problems that may have been created as described previously.

Unfortunately, the texture (air photo image overlay) is stored internally by ImageMaster and can't be transferred readily to the merged TIN. To view the composite 3D image with texture, you can simply display the two original TINs together. If texture is needed on the merged TIN, it can be created as follows. Add the photos needed to cover the merged TIN to the merged model in the Orientation mode as if you were starting a new model. Next, go into the folders where the orientation information for these photos is stored and copy the "*.imc", "*.ext", and "*.rel" files with names (*) that match the photos into the merge folder. This brings in the necessary photo orientation information. (Note that these must be photos that have gone through successful orientation; check your BundleResult.txt file to make sure they have.) Now go to Stereo mode, choose the image list tab and select the photos; then click on the arrow, select data type "TIN", and select your merged TIN. Finally, choose

“Measure”, “Texture”, “Texture Mapping”. Accept the default resolution. After processing you may have black areas that are gaps between photos; repeat the process with additional photos to fill the gaps. After the texture has been created, you can create an orthophoto for the merged model by the procedure outlined in step H2 above.

I. File Management

Image Master creates many temporary and intermediate file that can waste disk space. After you have completed work on a slump, go into each project folder (they are named the same as the project in Image Master). Find and delete the folders containing resampled stereo images; there will be one for each stereo pair used in the model generation, named after the two photos separated by an underscore, e.g. “DSC_8681_DSC_8682”. Also delete the “Pyramid” folder, which contains downsampled versions of your original photos for display purposes.

Standard Operating Procedure (SOP) # 5: 3D Model Analysis and Reporting (with Topcon Image Master software)
Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Area and volume computations

A1. Calculate the area of the slump. Calculate separate areas for the slump proper and fan for slumps with large fans. This involves drawing a polyline around each slump; the instructions below describe how to do this in Image Master. Area may also be calculated in ArcMap; see steps A4 through A6 below).

In Model mode, select Data, Polyline, Polyline (or hit the red line icon). Digitize a polyline around the periphery of the slump by clicking to create vertices. When you reach the last vertex, hit Close to snap the polyline closed.

Some tips on digitizing polylines in Image Master. The line is saved into the current (boldface) layer. Create a new layer (or use the default blank layer 0 and rename it later) so that the polyline doesn't get mixed up in your other layers. While digitizing, zoom with the mouse wheel and scroll by toggling on and off the pan (hand icon). To delete the last or last few vertices, use the undo button. To delete vertices after exiting, select them with the arrow tool, choosing "Polyline Vertex" as the data type, then use the delete key. If you need to stop digitizing a line and restart later, select it with the arrow tool (data type "Polyline"), then hit the "draw polyline" icon, and "OK" the query about continuing measurement of the selected polyline. The next point will snap to the vertex highlighted in red; if you want to work on the other end of the line, hit "Reverse". To move a vertex, choose "Data", "Polyline", and check "Move Vertex". This activates the mouse to choose a polyline, then a vertex to move, then a new position for the vertex. You can choose and move other vertices until you uncheck the "Move Vertex" command. To extend a polyline, first delete the segment you don't want by selecting the polyline, then choose "Data", "Polyline", "Divide", and select "Specify Side" and click on a line segment to delete it. Select the polyline again, hit the polyline icon and continue from the end (reverse if needed).

Finally, after you have a closed polyline encompassing the slump, switch to vertical view angle (click on the box with red top), then convert to 2D map view using the drop-down icon, select the polyline, and choose, "Data", "Area", "Polygon (Projected Area)".

A2. Calculate the change in slump volume relative to a reconstructed surface. This step is used to extrapolate a flat surface across the slump (a reconstruction of the pre-slump surface), and subtract the actual slump surface from it to estimate the total volume of material lost.

First, set up the necessary export files of your TIN. In Image Master, export the slump TIN as “*.tin file” (“File, Export, Shapefile, file format=.tin”). Note: if you have merged TINs, be careful to display only the merged tin if you have several (i.e., the components that went into the merger), and select to export only the current display. Next, display the outline of the slump on the new model: in the model with the perimeter polyline, shut off any other polylines to prevent their export (e.g., your cross-section line), select “File, Export, Shape File”, navigate to your export folder, choose “Save” as type DXF Files, name the file PassXXXperimeter.dxf or similar, “Save”, then under “Select data types to be saved” choose only “Polyline” and under “Selection by the display state” choose “Only Drawings currently displayed”.

Create a new model, and import the TIN file from the previous step into it. Rename the layer as “reconstructed” or similar; this is the one you will modify. Then import the TIN again; this is the one you will leave as is. You should see the two TINs as different layers. Next, import the dxf polyline files of the slump outline into your reconstruction model (“File, Import, Shape File”).

Now turn off the TIN that will represent the current surface so you can edit the “reconstructed” version. Use the polygon selection tool (button with polygon drawn with dashed lines) to delete vertices inside the slump (in the selection dialog box that appears, choose “TIN Vertex”; click to create the polygon, right click to finish). ImageMaster will automatically extrapolate the elevations across the deleted area. Use the slump outline as a reference and continue until you have deleted all of the TIN vertices in the slump. Tilt and pan the model to make sure you have a good smooth surface extrapolated across the slump. Then in Model mode, run “Data, Volume, Volume Difference”. Set the “reconstructed” TIN as the “Reference Surface” and the unmodified slump TIN as the “Object Surface”. Hit OK to get the volume difference

A3. Import a model into ArcMap. You will want to perform most analyses in ArcMap. In Image Master, save your TIN as a “dxf” file (“File, Export, Shape File”, check “TIN” only). Add the dxf file to an ArcMap project. Activate your 3D Analyst license by choosing “Customize, Extensions, 3D Analyst”. Start ArcToolbox and under “3D Analyst Tools”, open “TIN Management, Create TIN”. Under “Input Feature Class” choose the polyline version of your dxf file. This will create a TIN in ArcMap TIN file format. Convert the TIN to a DEM using the “TIN to Raster” geoprocessing tool (under “3D Analyst Tools, Conversion, From TIN”). Accept the default “Output Data Type” (FLOAT) and “Method” (LINEAR). The raster resolution is determined by the “Sampling Distance” entry; a raster resolution of 1 m (enter “CELLSIZE 1”) is suitable for most purposes. The orthophoto may be added directly into an ArcMap project.

To make it possible to make measurements, you need to define the coordinate system. Right-click on Layers, choose “Properties”, choose the coordinate system tab, then choose “New, Projected Coordinate System”. In the dialog box that appears, name it “local” and scroll down to the choice

“Local”. Accept the 1 meter linear unit, and under the “Geographic Coordinate System” choose “Select, North America, NAD83.prj.”

For simulated 3D viewing using ArcScene, add the ArcMap TIN and the orthophoto to an ArcScene project. To obtain the proper 3D effect, right-click on the orthophoto, choose “Properties”, choose the tab “Base Heights”, select “Obtain heights for layer from surface” and select your TIN. A4. Adjusting the registration. Sometimes the orthophotos and elevation model that is imported into ArcMap will be offset from other years. This occurs when tie points between years are difficult to locate. You can fine-adjust the registration in ArcMap using the Georeferencing toolbar. First georeference the orthophoto, using 3 or more control points. Then georeference the DEM made in step A3 above. Since landmarks are difficult to find on the DEM, match the corners of the DEM to the corners of the orthophoto to georeference the DEM.

A5. Digitize the main scarps in ArcMap. To illustrate change in the position of the main scarp over time, you will want to digitize the scarps and display them over orthophotos. With the orthophoto(s) displayed in ArcMap, use Arc Catalog to create a new polyline shapefile named after the slump ID, like “NOAT070scarps.shp”. In the “Create New Shapefile” dialog box, click on “Edit” under the coordinate system and define it as “Local” as described above. Choose this new shapefile layer to start editing and choose the line construction tool. Click around the scarp and double-click (or right-click and “finish sketch”) to end. To add to an existing line, simply use the line construction tool starting with a point snapped to the end of the existing line. After adding, use “Merge” on the editor bar to merge the two line under one record in the shapefile (so that the scarp for each year is one line). To delete part of a line, double-click on the line to bring up the “Edit Vertices” toolbar, select the “delete vertices” tool and use it to remove unwanted vertices. When the line for a year is complete, open the attribute table and type the year it represents in the “Id” field.

A6. Calculate the change in area since the last model. Two main scarp lines from different years can be joined to create a polygon that can be used to compute the area of new slumping and the average subsidence in the new part of the slump between the two years. First, create a polygon shapefile and start editing it. Next, make sure the two scarp lines digitized above touch to form a closed polygon. Select them using the editor toolbar select arrow, open the Advanced Editing toolbar (“Customize, Toolbars, Advanced Editing”), choose the “Construct Polygons” icon (wrench), and select the proper polygons shapefile, be sure the box “Use Existing Features” is checked, and hit OK.

To compute the area of this polygon, open the attribute table containing the polygon, click on the “Table Options” dropdown in the upper left corner, select “Add Field”, name it something like “AreaMsq” and set the type to “Double”, and (Note: you have to stop editing to add a field). Then right-click the new column, choose “Calculate Geometry”, select the Property “Area” (the default), and “OK”.

A7. Calculate volume change from last measurement. This should be done in ArcMap not Image Master. Image Master has a convenient function that will calculate the difference between two entire TINs (used above to compute the volume change to a reconstructed surface), but Image Master does not allow us to restrict this analysis to just the main subsidence area of the slump; we need to restrict

the area where the volume difference is calculated, to avoid errors due to minor elevation differences accumulated over a large area of the TINs.

Import two TINs from different dates into ArcMap as described previously (using the 3D Analyst TIN Management tool “Create Tin” and select the polyline dxf file as the source feature class). Convert the TINs to rasters using the “TIN to Raster” geoprocessing tool (under “3D Analyst Tools, Conversion, From TIN”; see step A3 above). Next subtract the two rasters from one another using the raster calculator (“Spatial Analyst Tools, Map Algebra”).

The difference between the two DEMs should be less than 0.5 m in places you know to be stable. If not, you may need to adjust the elevations on the DEM that is most suspect. A good way to accomplish this is to create a point shapefile and digitize points in places that you are certain should have not changed in elevation between the two DEMs. Avoid actively slumping areas and areas with tall (i.e. shrubby) vegetation. Next, write the values from the raster of differences between the two DEMs to the points using the “Extract Values to Points” geoprocessing tool (under Spatial Analyst tools, Extraction). Then, create a TIN from these points with the “Create TIN” geoprocessing tool (3D Analyst Tools, Data Management, TIN; choose RASTERVALUE as the Height Field). Convert this tin to a raster as in step A3 above. Finally, add or subtract this “correction raster” from the DEM you want improve (the decision to add or subtract it depends on how you computed the difference raster; if you get the sign wrong, the errors will be doubled instead of eliminated). Finally, re-compute the difference between the two DEMs.

Digitize polygons for zones to summarize. Typically we are interested in the total subsidence in the upper part of the slump and the total accumulation just below in slumps that have a bulge of material below the main subsidence area. Create a polygon shapefile using Arc Catalog; define a local coordinate system for it with meters as units. Digitize the area of subsidence, referring to the difference raster created in the previous step and the orthophotos while digitizing. It helps to define a color scheme for the elevation difference raster with distinctive colors for areas with slightly positive and negative change in elevation, so you can digitize the zero line. If the slump has a zone of accumulation (increase in elevation), digitize the outline of this too. Reminder: the tool to append a polygon that borders an existing polygon is called “Auto Complete Polygon” under “Construction Tools” of the “Create Features” menus that pops up when you start editing.. Add a column to the attribute table of this polygon layer and label it “direction”. As you digitize the polygons, populate this attribute as “down” or “up” to indicate the direction of surface movement.

Summarize the subsidence. Run “Zonal Statistics as Table” (under “Spatial Analyst Tools, Zonal”), with a polygon shapefile defining the area of interest under “Input raster or feature zone data”, and the “Input value raster” is the raster with the elevation differences between the two dates. For the zone field, use the column you used to label the up/down direction of movement of the surface. Give the output table a *.dbf extension to avoid getting an ArcMap table. The total subsidence volume is given by the SUM column, in units of meters if you chose the raster cellsize of 1 m in step G7.1 above.

Typically you will also want to run zonal statistics for the polygon that outlines the two main scarps, to compute the average subsidence in the new slump area. Divide the output of the zonal statistics table SUM by the new area of the slump computed previously to get the average new subsidence.

B Plotting Cross-Sections

B1. Generate cross-sectional data in Image Master. We will typically plot a longitudinal cross-section of the whole slump and sometimes a close-up cross-section of the main scarp. In Model mode, choose the “Create Cross Section Data” icon (small red graph). Click on the start and end points for the cross-section (for consistency in the plots, click on the upper end first). When you have a cross-section that you want to keep, in the Cross Section dialog box click “Register” to save the location of the cross-section, and click “Save” (and select “Paper Coordinate System X-Y”). Name the file after the pass that was used to create it. The cross-section data will be saved as a dxf graphics file.

A plot of two years’ cross-sections superimposed upon one another is very useful for visualizing change. To do this, you need to get the TINs with textures into a single Image Master model. Open each model and export the TIN with texture using Image Master’s “tin” format (File, Export, Shape File, change Save as type to TIN files. Then create a new model named after the two passes it will contain and import the TINs (in Model mode, “File, Import, Shape File”, navigate to your TIN file, “OK”). Next generate a cross-section using the “Create Cross Section Data” icon as described above, Register (to save the location) and “Save” (to export the data). The exported *.dxf file will contain both cross-sections.

B2. Convert the cross-section data to table format. Typically, we will want to reformat the cross-section data in order to plot it using R or spreadsheet software. The cross-section dxf file produced by Image master is a text file with consecutive lines that represent points, starting with VERTEX, followed by the x and z coordinates along with some other numbers, and ending with “0”. These can be reformatted into a comma-delimited tabular format with the following Python script:

```
# ConvertDxfToTable.py
# Program to read a dxf file containing a topographic cross section
# exported from Image Master
# and convert it to a table for plotting in other software
# The resulting table has numerous columns, most containing
# tags/delimiters that can be deleted in a spreadsheet
# ...but there are two actual data columns, distance and elevation, that
# are readily recognized and plotted
#-----

# Edit the input file name below as needed:
infile = "Pass10B-Section.dxf"

outfile = infile + "Table.csv"

indata = open(infile, "rb") # read binary to allow access to both line
delimiters, cr and nl
table = "" # this variable will hold the

for line in indata: # iterate through the dxf file one line at a time
```

```

        if line[:-2] == " 0": #there is a line containing "sp sp zero cr nl"
at the end of each record of data
            item = line[:-1] #retain the new line characters after these
lines
        else:
            item = line[:-2] + "," #all other lines become comma-delimited
items in a table
            table = table + item #append to a long string containing all of the
processed data

outdata = open(outfile, "w")
outdata.write(table)
outdata.close()

```

Copy this code into a text editor, edit the input file name at the start, and save with a *.py extension file in the same folder as the dxf file. Start the Python IDLE editor, open the script, and run.

Open the resulting file csv file in a spreadsheet to view a table resembling the following:

0								
SECTION	2	HEADER	9	\$EXTMIN	10	0	20	17.94
ENDSEC	0							
SECTION	2	TABLES	0					
TABLE	2	LAYER	70	1	0			
LAYER	2	CrossSection	70	64	62	1	6	CONT
ENDTAB	0							
ENDSEC	0							
SECTION	2	BLOCKS	0					
ENDSEC	0							
SECTION	2	ENTITIES	0					
POLYLINE	8	CrossSection	66	1	10	0	20	0
VERTEX	8	0	10	0	20	0.606283	30	0
VERTEX	8	0	10	4.53566	20	0.366733	30	0
VERTEX	8	0	10	6.375638	20	0.281154	30	0
VERTEX	8	0	10	9.689359	20	0.120015	30	0
VERTEX	8	0	10	9.822053	20	0.112005	30	0
VERTEX	8	0	10	9.898435	20	0.104618	30	0
VERTEX	8	0	10	12.93524	20	-0.26511	30	0
VERTEX	8	0	10	15.16591	20	-0.41127	30	0
VERTEX	8	0	10	17.96448	20	-0.60748	30	0
VERTEX	8	0	10	20.3091	20	-0.77155	30	0
VERTEX	8	0	10	23.58343	20	-0.97524	30	0
Etc.		continuing						

Delete all except the x and z coordinate columns (the columns with decimal numbers in “VERTEX” rows, highlighted in yellow) and label the two columns with headers “dist” and “elev”.

If you have more than one cross-section (e.g., you had two models open when you plotted the cross-section), they will appear consecutively in the data file with a short gap in between, unfortunately without labels. Inspect the table produced by the Python script and locate the place midway down where the second cross-section’s data starts (shown below in pink; the first section is highlighted yellow):

```
Continuing from above
VERTEX      8      0      10      213.7706      20      5.306353      30      0
VERTEX      8      0      10      214.8336      20      5.40662      30      0
VERTEX      8      0      10      215.0133      20      5.424234      30      0
VERTEX      8      0      10      215.0855      20      5.428537      30      0
VERTEX      8      0      10      216.1868      20      5.430647      30      0
SEQEND      0
POLYLINE    8      CrossSection      66      1      10      0      20      0
VERTEX      8      0      10      176.5102      20      3.531749      30      0
VERTEX      8      0      10      175.8295      20      3.513971      30      0
VERTEX      8      0      10      174.4103      20      3.449948      30      0
VERTEX      8      0      10      168.0594      20      3.028629      30      0
VERTEX      8      0      10      167.4183      20      2.987522      30      0
Etc. continuing
```

Delete the extraneous columns and lines, label the columns “dist” and “elev”, and add a new column “yr”. Populate the “yr” column with “1” for the first year and “2” for the second and ditto down all the rows of data.

```
Dist      Elev      yr
(long gap in here with data)
213.7706  5.306353      1
214.8336  5.40662      1
215.0133  5.424234      1
215.0855  5.428537      1
216.1868  5.430647      1
176.5102  3.531749      2
175.8295  3.513971      2
174.4103  3.449948      2
168.0594  3.028629      2
167.4183  2.987522      2
Etc. continuing
```

Save as csv (comma-delimited). Note that at this point you do not know which year is 1 or 2; that will be determined later.

B3. Plot cross-sections using R statistical software.

B3.1. Cross-sections with one year of data. Import the data prepared above into R's default data table "Dataset" and name the columns "dist" (distance along the cross-section), and "elev" (elevation). For data tables with one cross-section, the following R code produces a convenient plot in png file format.

```
png(file="C:/GIS/GISdataLocalBackup/SlumpMonitoring/ImageMasterProjects/NO
AT070/ExportFiles/NOAT070xsect.png",width=1200,height=650,res=200)
plot(Dataset$dist, Dataset$elev, type="l", lty=1, xlab="Distance, m",
ylab="Elevation, m")
dev.off()
```

The first line defines the output file path and name and dimensions and resolution of the file. *Edit the output file path name in the first line of the script* as needed, and run. The second line runs the "plot" command, defining the variable names, plot and line types, and axis labels. The resulting png file can be readily inserted into a report. For an immediate display and no output file, omit the first and last lines of the script.

B3.2. Cross-sections with two years of data. The dxf file is converted to table format using the Python script as described above. Then open R and import the data, with columns labeled "dist", "elev", and "yr" as described previously. The following R script will plot the two years of data with different symbols:

```
png(file="C:/Documents and Settings/DKSwanson/My
Documents/VitalSigns/Permafrost/3Dmodeling/SlumpMonitoring/ImageMasterProj
ects/NOAT070/2010/ExportFiles/NOAT070Changexsect.png",width=1200,height=65
0,res=200)
yr1 <- subset(Dataset, yr == 1)
yr2 <- subset(Dataset, yr == 2)
plot(yr1$dist, yr1$elev, type="l", lty=1, xlim=c(min(Dataset$dist),
max(Dataset$dist)), ylim=c(min(Dataset$elev), max(Dataset$elev)),
xlab="Distance, m", ylab="Elevation, m")
lines(yr2$dist, yr2$elev, type="l", lty=2, xlab="Distance, m",
ylab="Elevation, m")
legend("bottomleft", bty="n", lty=c(1, 2), legend=c("2010", "2011"))
dev.off()
```

As before, the first line defines the output file; *edit the output file path name as needed*. The script uses the default R table Dataset with columns labeled "dist" (distance again), "elev", (elevation), and "yr" (year). The second and third lines of the script define temporary tables of data ("yr1" and "yr2") containing only year 1 or year 2. *If your plot comes out with the year labels exchanged, switch the names of the temporary tables here*. The "plot" command plots solid lines (lty=1) for year 1 data, defines the limits of the plot to the whole original data set, and labels the axes. The "lines" command plots the year 2 data using dashes (lty=2). The legend command labels these line types in the bottom

left corner of the plot; *you will have to edit the years here to match yours*. The “bty” command eliminates the box that would be printed around the legend.

C. Reporting Results

C1. Flight and photo parameters. Report the following parameters for each pass, extracted from BundleResult.txt:

C1.1. Camera elevation, m: compute the mean, minimum, and maximum of Zo from the Camera Locations section

C1.2. Camera angle in degrees from vertical: compute the mean, minimum, and maximum of Phi from the Camera Locations section

C1.3. Distance to target, m: compute the mean, minimum, and maximum of Height [m] from the “Stereo Camera Conditions and Ground Resolution” section (end of the BundleResult.txt file)

C1.4. Base:height ratio: compute the mean, minimum, and maximum of B/H Ratio from the “Stereo Camera Conditions and Ground Resolution” section

C1.5. Control point error in x, m: report the mean and maximum error in the x direction. This is under the “Calculated Coordinates” section. The first column after “Standard Deviation [m]” is the mean square error of x in meters; below this after “Maximum Residuals [m]”, the first number is the worst error in the x direction.

C1.6. Control point error in y, m: report the mean and maximum error in the y direction. This is under the “Calculated Coordinates: section, as for x, except the 2nd column.

C1.7. Control point error in z, m: report the mean and maximum error in the z direction. This is under the “Calculated Coordinates: section, as for x, except the 3rd column.

C2. Explanation of camera angles nomenclature. Omega, Phi, and Kappa are defined in photogrammetry as the rotation of the camera around its x, y, and z axes, where x is the long dimension of the photo, y the short dimension, and z perpendicular to the photo plane. In this project the camera is held with its long axis perpendicular to the flight line (“portrait” orientation), so Phi is of greatest interest because it describes how oblique the view is. In Image Master, Phi is reported as a negative number, and it is the angle measured up from vertical. Omega should be small and represents the rotation around the camera x-axis, i.e., the amount the camera faced forward or backward along the flight line. Kappa represents the rotation of the long axis of the camera from the flight line; it should be large (near -90°) for our “portrait” camera orientation.

C3. Modeling results. Use orthophotos, cross-sections, 3D images, and selected oblique photos and snapshots to illustrate slump morphology and change. Effective ways to portray change include elevation difference maps, and overlay of the outline of the slump from a previous visit onto the most recent orthophoto. Reporting the amount of main scarp retreat and volume change computed above.

Standard Operating Procedure (SOP) # 6: Create and Analyze 3D Models Using Photoscan and ArcGIS Software

Version 1.0 (Jan 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A Background

This SOP describes how to create a 3D model from a set of overlapping aerial photographs using Agisoft Photoscan software version 1.2. Step C has variations for photos with and without detailed camera coordinates. Step D describes how to georeference a 3D model that was created from a set of photographs that lack camera coordinates, using an existing model (orthophotograph and digital elevation model - DEM). The reference model may be obtained from a contractor or produced locally using Photoscan with detailed camera coordinates. Step D may be omitted when the photos have accurate camera location coordinates.

B Clip the georeferenced slump model from a larger data set

B1. Our area of interest (i.e. a retrogressive thaw slump) may occupy only a small part of a large 3D model (DEM and orthoimage). To improve performance during analysis, it is convenient to clip just the vicinity of the slump from the larger model.

B2. Create an ARCN GIS project, add the georeferenced DEMs and orthoimage. Create a polygon shapefile called "ClipBox.shp" and draw a rectangle big enough to cover the slump and at least 100 m of surrounding terrain.

B3. Use the "Clip" geoprocessing tool (under Data Management, Raster, Raster Processing) to clip out the slump of interest from both the orthophoto and DEM. The Output Extent is the clip box created above. Save the result as a tif, using the naming convention slump ID, year, and "ortho" or "DEM, e.g. "NOAT148_2016ortho.tif".

C Create a 3D model

C1. The following procedure may be used for vertical or oblique photos. Ideally we will include all the available photos from a single date in the model, including multiple aircraft passes made with various flight paths. Sometimes Photoscan is unable to match oblique photos from passes with very different perspectives. A satisfactory model may be made from a single pass if photos overlap sufficiently, but in general we want to use as many overlapping photos as possible.

C2. Open Photoscan and create a project named for the slump and year. Under the "Workflow" menu, use "Add Photos" to navigate to and select photos. Photoscan will automatically create a "chunk", which is a group of photos processed together into a model. Right-click the chunk and rename the chunk after the passes it includes (A, B, etc.) if you don't use all of the photos. Use the "Add chunk" icon to create another chunk if you want to try processing a different group of photos.

C3. Check the Reference tab for your photos and see if the photos came in with coordinates read from the photos' Exif data. If so and they are latitude/longitude coordinates, convert them to UTM using the Convert button (calculator icon) and change to NAD83/UTM zone 4N or 5N as appropriate, and hit OK. Check the accuracy and adjust if needed. The accuracy will vary with the GPS system used. Older navigational GPS coordinates without WAAS correction had accuracies in the 10s of meters. WAAS-corrected GPS is typically 1 to 5 m. Dual-frequency and differentially corrected GPS attain accuracies of less than 1 m.

C4. If accurate camera coordinates (less than 1 m error) were imported with the photos (see step C3 above), skip to step C5. Or, if accurate coordinates are not available, skip to step C5. If accurate camera coordinates are available in an external file, copy the photo filename, x, y, and z coordinates (in meters, UTM coordinate reference system) into a text file and save in the directory with your Photoscan project. Open the Reference pane using the tab at the bottom right of the screen and choose the Import toolbar button (icon is a small grid with open folder in front of it). In the dialog box that opens, choose the coordinate system NAD83/UTM zone 4N, the appropriate delimiter for your text file, uncheck "Load accuracy" and "Load orientation" and hit OK. Open the Reference settings dialog box (crossed wrench and hammer icon) and set the coordinate system to NAD83/UTM zone 4N. Set the camera accuracy (m) to what you think your accuracy is.

C5. Under "Workflow", run "Align photos", with "Generic" pair preselection and "high" accuracy ("medium" may be needed for a slower computer and a large number of photos). This will generally supply enough points for us to create a 3D model

C6. Run "Workflow", "Build Dense Cloud" with the "Low" quality setting, and use this to create the mesh in the next step.

D Register the model to real-world coordinates.

D1. Complete this step only for models created without accurate camera locations. If you imported accurate camera locations in steps C3 or C4 above, your model is already georeferenced and you may skip to section E.

D2. Open the georeferenced orthophoto and DEM from step B in ArcGIS in one window and Photoscan with the unreferenced model from step C in another. You will search for objects on the Photoscan model that you can also locate on the georeferenced orthophoto in ARCGIS. The resolution of the texture on the mesh may be too coarse to recognize small landmarks. If so, run "Build Dense Cloud" with the "High" quality setting. This will take some time, but the resulting dense cloud of colored points should provide enough detail to find landmarks.

D3. If this is the first time you have used a particular georeferenced model to register another, create a point shapefile in ArcGIS and name it after the slump, e.g. NOAT148regPts.shp. Its coordinate system should be the same as the model it lies on (NAD83 UTM zone 4N for most of NOAT, 5N for most of GAAR). Add a new field called "pointID", type Text, length 10. Digitize the points in Photoscan by right-clicking on the chosen location and selecting "Create New Point". Find the same point in ARCGIS and digitize it also. Note the point identifying number from Photoscan and fill it in the pointID field of the shapefile. Continue until you have at least 8 points around the periphery of the slump. When finished, open the attribute table in ArcGIS and add two new fields, UTMx and UTM y. Right-click the column header and choose "Calculate geometry", then in the dialog box that appears, "Property: of X Coordinate of Point" or "Y Coordinate of Point" as appropriate. This will fill in the UTM coordinate of the point. What remains is to get the Z coordinate off the DEM. Find the geoprocessing tool "Extract Multi Values to Points" (Spatial analyst tools, Extraction) and run it to add a column with the elevations. While we usually have only one elevation column to add, this tool adds the new data to the existing table without creating a new shapefile.

D4. If a shapefile of reference points has already been created for your georeferenced model, then you may simply view it in ArcGIS while creating points of the same name in Photoscan.

D5. Refine point locations in Photoscan. Points can be located more accurately on original photos than on the point cloud in Photoscan. Do the best you can to locate each point on the point cloud, and then right-click on the point and choose "Filter photos by marker". Now just the photos where that marker occurs will appear on the bottom of the window, with your approximate location shown on each. Double-click the photos and drag the point to a better location if you can. The point will change from blue to green color if you have refined it. If you can't see the marker's location clearly on a photo, don't update it; instead, right-click it and choose "Remove marker". It will change to gray. If you are unable to locate the point accurately in any photo, uncheck it in the Markers window. Any leftover blue markers will adversely affect the optimization, so either remove them manually, or run this Python script to remove any that are left when you have finished checking them:

```
import PhotoScan

doc = PhotoScan.app.document
chunk = doc.chunk

for marker in chunk.markers:
    for photo in list(marker.projections.keys()):
        if not marker.projections[photo].pinned:
            marker.projections[photo] = None
            print("Projection for "+marker.label + " removed on " +
photo.label)

print("Script finished")
```

To run the script, copy this to a text file and name it "RemoveBlueMarkers.py" or similar. Then in Photoscan, under the Tools menu select Run Script, navigate to the script, and hit OK to run (it has no arguments).

D6. Open the attribute table of your reference points shapefile in ArcGIS and click on the small menu in the upper left corner, choose "Export..." and then export as a text file named after the slump plus "refPts.txt". Then in Photoscan, choose the reference tab and the icon to import reference data from a file. In the resulting dialog box choose the coordinate system "NAD83/UTM zone 4N (EPSG::26904)" and the appropriate delimiter (comma), then adjust "Start import at row" to 2 and the column numbers so that they match your data. Hit OK and the coordinates should appear in the Markers table.

D7. Open the Settings (crossed tools icon) on the Reference pane toolbar and be sure the coordinate system is set to UTM as described above. Also estimate the accuracy of your Markers. These are typically about 0.5 m and 5 pixels, though it varies greatly on oblique photos between near and distant points. Photoscan will automatically adjust the model to match the coordinate system of the points. To further adjust the model to match the control points, hit the optimize button (magic wand) on the Reference pane. This will wipe out your existing dense cloud and mesh. Check your marker point errors and adjust any that are more than a meter or two off.

D8. Create another dense point cloud (since your first one was destroyed by the previous step), this time using the Low or Medium quality setting to save time. This dense point cloud will be used to create the DEM.

E. Create and export a DEM and orthomosaic

E1. If needed, adjust the bounding box around the new model to include only the slump and nearby areas of interest. This requires use of the Resize Region icon (crossed arrow on the main menu bar). Then open Workflow, Build DEM, accept the defaults (Dense cloud source data, Interpolation Enabled, and Point classes: All). When the DEM appears in your Workspace, right-click and choose Export DEM, Export tiff; check the "Write World file" box. If you had low-resolution photos and the default DEM resolution is more than 1 m, change the export pixel resolution to 1 m. Name the export file after the slump, year, and pass, e.g. "NOAT148_2012Adem.tif" and save as a GeoTIFF.

E2. Next create an orthomosaic. An orthomosaic can be projected onto either the DEM just created or a new mesh created from the points cloud. We will normally use the DEM as the surface for the orthomosaic. Run Workflow, Build Orthomosaic, choose the DEM surface and Mosaic blending mode. A pixel size of 0.1 m is generally sufficient. Accept the other defaults and run. Right-click the result and select Export jpg/tif/png, accepting the defaults. The existing DEM should be fine, but if desired you can create the mesh (using Workflow, Build Mesh, with surface type Height field, Source data Dense cloud, and Face count Low) and project the orthomosaic in this.

F. Save the Photoscan processing report.

After Photoscan processing is completed for a given slump and imagery year, create the standard Photoscan processing report. In Photoscan under File, choose Generate Report, accept the defaults in the "Generate Report" dialog box, hit OK, and in the "Save as" dialog box name the report after the slump ID and year.

G. Compute and correct elevation change between dates

G1. Add the DEM and orthomosaic from step E to the ArcGIS project with the other 3D model(s) obtained from a contractor or produced previously. Under "Geoprocessing" choose "Environments", "Raster Analysis", "Cell Size", change to "Minimum of Inputs".

G2. Use the Raster Calculator (Spatial Analyst Tools, Map Algebra) to subtract the earlier DEM from the later one (i.e. DEM2 - DEM1 where 1 and 2 are different dates in sequence). The areas that subsided receive negative signs for change. In Raster Calculator, set the raster environment setting to preserve the resolution of the finest raster: click on "Environments..." and under "Raster Analysis" set the Cell Size to "Minimum of Inputs".

G3. Inspect the difference raster. There will often be a systematic bias in the data that causes large zones that shouldn't have changed to show a difference of 0.5 m or more between dates. We will correct for this systematic bias as follows.

G4. First, downsample the difference raster to a coarser resolution to make computations easier, using the "Aggregate" geoprocessing tool (Spatial Analyst Tools, Generalization). A resolution of 3 to 5 meters should be sufficient. Adjust the cell factor, e.g. with a cell factor of 10 the new resolution will be 10 times coarser than the original, and use MEAN as the aggregation technique. Give the output a temporary name, e.g., tmp.tif.

G5. Next convert this raster to points using "Raster to Point" (under Conversion Tools, From Raster) and save the result as a shapefile. Adjust the display settings for the points to make the resulting points smaller so you can see an image behind them, and put the orthoimage of later date and the "difference" raster behind the points. Start editing the point shapefile and delete the points wherever the elevation might have actually changed between the dates. The "Select by Polygons" tool is useful for this purpose. You will need to delete all points from the active part of the slump. Also, areas of dense shrubs may need to be deleted if they show a false ground surface elevation change because one image is leaf-on and the other leaf-off. Your goal is to keep all the points that represent error and delete all the points that actually experienced change in elevation between the two dates. When finished, save the point shapefile.

G6. Run the "IDW" tool (Spatial Analyst Tools, Interpolation) to generate a smooth surface from the points. IDW interpolates a raster surface from points using inverse distance weighting. Use GRID_CODE (the elevations) as the Z value field. Save the result as a tif file with the years and "idw" in the name. An output cell size of 2 m should be adequate. Set the Power setting to 2 and the Search radius as Variable with Number of points: 24. A variable search radius is needed because the size of the gap we need to fill can vary. The power setting determines the relative influence of near vs. far points, by controlling the exponent on the weighting function (which is the reciprocal of distance). A power of 2 means the influence drops off with the inverse square of distance, which has some appeal because areas of equal distance from the point have equal influence. The resulting correction raster should interpolate smoothly across the region with no correction point data. If there are abrupt transitions instead, try running IDW with a fixed search radius large enough to span the no-data area.

G7. Subtract the "idw" correction raster from the original difference raster (using Raster Calculator) to get a corrected change raster, and save as a tif with "cor" appended to the name. Your "idw" correction raster has coarser resolution than the original DEMs which will carry over to the result here unless you changed the "Cell Size" environment setting as instructed above. Check in the Raster Calculator: click on "Environments..." and under "Raster Analysis" make sure the Cell Size is "Minimum of Inputs".

H. Summarize changes

H1. Digitize the slump outline and compute the area. Create a new polygon shapefile named after the slump ID if one doesn't already exist. Add columns for "date" (long integer) and "area_msq" (double). Dates are in the format YYYYMMDD. Display the slump perimeters shapefile over the orthophoto. Start editing, and digitize the outline of the slump. This encompasses the whole area disturbed by slumping, including deposition of material below. We save overlapping polygons of the whole slump each year. For portions of the slump that were digitized previously and haven't changed, simply copy the previous outline and edit it. To copy, with the polygon shapefile in edit mode, select an existing perimeter and use the copy and paste commands on the main menu, and save. Then with your copy selected, display the new year's orthophoto and use either the Cut Polygons Tool (to digitize an earlier year by digitizing a new line inside the old polygon) or the Reshape Features Tool (to digitize a later year by enlarging the polygon). After you use the Cut Polygons Tool, you will have to delete the sliver polygon that represents the later year's growth. Don't correct minor changes due to photo registration errors. For slump boundaries that consist of fracturing turf without a steep scarp, put the slump boundary along the first fracture that you encounter when approaching the slump from undisturbed ground.

When finished digitizing, right-click the "area_msq" column, choose "Calculate Geometry", select the Property "Area" (the default), and "OK" to compute the area of the slump.

H2. Measure the linear distance of slump scarp change. This distance can be approximated by using the ruler measuring tool in ArcGIS. Or, to obtain a systematic quantitative measurement of the distance between successive scarps, select the outermost (most recent) polygon in the slump outline shapefile. Then run the "Feature Vertices To Points" geoprocessing tool (under Data Management Tools, Features). The output will be points at all the vertices in the outmost polygon. Now select one of the other years in the slump outline shapefile, and run the "Near" geoprocessing tool (under Analysis Tools, Proximity). The tool will compute the closest distance from each vertex point to the chosen slump outline polygon.

H3. Calculate the volume change between two models. Create a new polygon shapefile called "volume_zone.shp" or similar and start editing it. Select the slump perimeter polygon (from step G1) for the later year of the two you are comparing, and copy it into "volume_zone". If part of the slump has become inactive (e.g. the lower part in many slumps), use the Cut Polygons Tool to divide off the inactive part of the slump; delete the inactive areas, save, and exit editing. We omit the inactive part of the slump to avoid summing small elevation difference errors over large areas, which would add

error to our volume computations. Next, open the Raster Calculator (Spatial Analyst Tools, Map Algebra) and enter this formula:

```
Int(("NOAT148_2013_10diffcor.tif" * 10) + 0.5)
```

The tif file in this formula is the corrected different raster between the two dates of interest and must be modified to match yours; it may be chosen from the tool menu. Enter a temporary output file name. Hit the "Environments..." button and open the Raster Analysis settings. Under "Mask" choose the "volume_zone.shp" that you just created and hit OK. A new raster will appear with just your active slump zone. The "Int" operator in the raster formula will create an integer raster, which will have an attribute table called *vat.dbf. Open this table in ArcGIS and you will see the change amounts in meters times 10 (and rounded to an integer) under Value and the number of pixels with that amount of change under Count. Below is an example; the top data row is the count of pixels (6) that had change amounts that rounded to -5.5 m, the second row shows that 173 pixels had changes that rounded to -5.4 m etc.

OID	Value	Count
0	-55	6
1	-54	173
2	-53	1257
3	-52	1428
4	-51	1755
5	-50	1809
etc.		

Create a new column by choosing the menu in the top left corner of the table and selecting "Add Field". Call the new column "volume", assign its type as "Double". Right-click the new column, choose Field Calculator, and enter

```
[Value] * [Count] * (px^2)/10
```

where *px* is the pixel size of the raster. You can look this up in the raster's properties on the Arc GIS table of contents under "Source" and "Cell Size (X, Y)". The new column will give the volume change represented by each row.

Open the *vat.dbf in your spreadsheet and use the =SUM() function to compute the sum of all negative change volumes, the sum of all positive change volumes, and the sum of all changes (the net volume change). Most changes are negative (subsidence), but positive changes can occur if material is transported and accumulates downslope. The row with zero value represents pixels with changes (in units of meters times 10) that rounded to 0, i.e. from -0.05 to +0.05 m. If large areas with no "real" change (i.e. areas where the difference between the DEMs is all registration error) are included in our analysis area ("volume_zone.shp"), errors can inflate our sum of positive or negative change volumes. Thus it would be prudent to also exclude the rows labeled -1, and +1 in addition to the 0 row, and perhaps -2 and +2 also. In the latter case we would be excluding all areas that registered

changes between -0.25 and +0.25 m, which, given our current topographic mapping precision, are effectively indistinguishable from zero.

H4. Time scale for changes in volume and area. To normalize the amount of actual thaw time that separates successive slump models, compute the sum of thaw degree-days that separate any two sample dates. Data may be obtained for the climate stations in Fig. 4 nearest a slump by the procedures outlined in Appendix A, SOP #3. Compute the running sum of thaw-degree days above 0 °C from daily data and look up the date of each photo sample.

I Plot Cross-Sections

I1. Generate a cross-section data in ArcGIS. Create a shapefile that defines the line where you would like cross-sectional data. It is OK to include one or two "doglegs" in the line. Name it after the slump and ending with *.shp. Next, add elevation data from one of your DEMs to the line using the "Interpolate Shape" tool (under 3D Analyst Tools, Functional Surface). The Input Surface is your DEM, the Input Feature Class is the line you just digitized. Name the output after the slump and year, ending with *.shp again. Leave the defaults for the other blanks in the tool. Select the resulting shapefile and "Start Editing" again. Add the 3D Analyst toolbar if you haven't already and select the profiling tool, "Profile Graph". It will generate a profile graph for your line. You will probably want to export the data so you can plot multiple years together. To do this, right-click the profile graph and choose "Export". Choose the "Data" tab and Text or Excel output format. Open in your spreadsheet and make cross-sectional plots.

Standard Operating Procedure (SOP) # 7: Ordering aerial photographs, orthomosaics, and digital elevation models
Version 1.0 (Jan 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background

This SOP describes the specifications for small-format vertical aerial photos, orthomosaics, and digital elevation models (DEMs) used for change detection on thermal erosion features.

B. Specifications

Photo format: we prefer to receive both jpg and a lossless format, but jpg alone is adequate. Conventional cameras that record visible red, green, and blue light are adequate.

Photo orientation: the camera should be oriented so that the short side of the camera frame is parallel to the flight path. The flight direction of the aircraft may be chosen for convenience and safety. Best results are usually obtained if several parallel flight paths cover the area of interest, with occasional paths perpendicular to the trend of the others.

Adjacent photo overlap: 80% end lap (overlap along the short dimension of consecutive photos) and 60% side lap (overlap between adjacent lines).

Photo resolution: pixel size as measured on the ground should be about 10 cm.

Photo season: photos should be taken in the summer or fall such that they are snow-free or only semi-permanent snowbanks remain. Photos may be taken during the leaf-on season or after leaf-drop in the fall.

Sun angle: photographs should be taken with a sun angle of at least 20° above the horizon. See ESRL Global Monitoring Division (2016) for solar angle calculations.

Photo GPS location data: camera coordinates (x, y, z) should be accurate to within less than 50 cm and preferably 10 cm or better. Coordinates should be written into the photos' exif metadata and supplied in table form at WGS84 latitude and longitude, and UTM.

Orthomosaic and DEM file format: geotif, UTM coordinate reference system.

Orthomosaic resolution and locational accuracy: resolution 20 cm or less, locational accuracy 30 cm or less

DEM resolution and vertical accuracy: 50 cm or less

Section C Literature Cited

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D. Standard Operating Procedures for Monitoring Ice-Wedge Degradation

These are standard operating procedures for monitoring ice-wedge degradation, as described in Section 5 of the protocol narrative document (Swanson 2017) and Swanson (2016).

Table D1. Deliverables schedule for monitoring of ice-wedge degradation

Identifier	Deliverable	Format	Schedule	Responsibility	Description
D1	Imagery for ice-wedge polygon analysis	raster	Every 10 years starting in 2008 or 2009	PI	High-resolution (1 m or finer) satellite imagery
D2	Footprint layer	GIS shapefile	Within 6 months of receipt of imagery	PI	GIS polygons indicating the boundaries of the area within each new image used to map water associated with ice-wedge polygons, and the threshold value used to map water on the image.
D3	Sample plot center points	Database records	Within 6 months of receipt of imagery	PI	Coordinates and plot IDs of sample plot centers in any new study areas
D4	Ice-wedge polygon center points	Database records	Within 6 months of receipt of imagery	PI	Updated ice-wedge polygon centers
D5	Ice-wedge polygons visual classification	Database records	Within 6 months of receipt of imagery	PI	Classification of ice-wedge polygons on new imagery
D6	Ice-wedge polygon zones	GIS shapefile	Within 6 months of receipt of imagery	PI	GIS polygons that encompass the ice-wedge polygons within sample plots
D7	Water pixel center points	Database records	Within 6 months of receipt of imagery	PI	Coordinates of centers of pixels mapped as water on new imagery, and associated distance indices used to determine the location of the water relative to the ice-wedge polygon centers
D8	Summary report	Document file (pdf)	Within 9 months of receipt of imagery	PI	Either an NPS Natural Resource Report or peer-reviewed journal article

Standard Operating Procedure (SOP) # 1: Historical aerial photograph georeferencing Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background

We use a projective transformation, which can achieve very good georeferencing without orthorectification in flat terrain such as our polygon study areas. The information needed for a projective transformation is stored as coordinates of a set of points tie points saved as a text file. We use a three-step georeferencing process to: 1) approximately locate the original photo and create a world file; 2) create of set of tie points to make a better, projective transformation; and 3) export the transformed image data, resampled to a standard 1 m pixel size.

B. Initial georeferencing

Add the historical photos covering the area of interest to an ArcMap project. Build pyramids if needed (see the geoprocessing tool “Batch Build Pyramids” under Data Management, Raster, Raster Properties).

Georeference each photo approximately using the ArcMap Georeferencing toolbar (if needed, add it using “Customize, Toolbars”). You can use just 3 or 4 points here and a low-resolution reference image (such as a Landsat mosaic) to speed up this process. Remember to select the correct image in the georeferencing toolbar and “Update Georeferencing” when completed. ArcMap 10.x (c. 2015) behaves erratically during georeferencing. The second tie point is often placed erroneously and must be deleted after other points have been located. Frequently the photo will revert to its original position after you “Update Georeferencing”. To correct this situation, delete the original (inaccurate) world file (*.tfw) and rename the newly created world file (*.tfwx) to *.tfw. Be sure you have set ArcMap to read worldfile (Customize, ArcMap Options, Raster Dataset, check “Use world file to define the coordinates of the raster”), then remove the photo from your ArcMap project and re-add it.

C. Refine georeferencing with projective transformation

Display the photo to be georeferenced along with the high-resolution, orthorectified satellite image to which it will be referenced, and select it on the Georeferencing toolbar. Find 10 well-distributed tie points between the photo and the satellite image. Use features that do not change between photo dates; ice-wedge polygon boundaries are good, while shoreline features on thermokarst lakes, and stream floodplain features are generally not reliable tie points. As mentioned above, the 2nd tie point

will often need to be deleted and re-located. Hit the “View Link Table” icon on the georeferencing toolbar to track your progress. After you have 4 or more points digitized, you can choose the projective transformation. Points with the highest residual are usually the worst ones, although some points with high residuals can be valid points upon close inspection and can help improve the georectification even though it lowers the total RMS error. You should be able to find 10 points that all have residuals of 2 m or less, and a total RMS error of 1 m or less.

After digitizing the 10 points, hit the “Save” icon and name the text file after the image name. *Do not* “Update Georeferencing” as that will erase the points. With these saved points you can, if needed, reload and refine the georeferencing later by opening the link dialog box and opening the text file of saved points, and choosing "Projective Transformation" again.

Georeference every photograph (in the set of overlapping photos) so that only the center of each photo is needed to cover the study area. Distortion and vignetting (the tendency for image corners to be darker) are minimized in the photo centers.

D. Export georeferenced and downsampled image

From the Georeferencing dropdown, select "Rectify". In the "Save As" dialog box that appears, chose Cell Size: 1, NoData as: 256 (default), Resample Type: Bilinear Interpolation, Name: the image name with "*.tif" changed to "*rect.tif", Format: TIFF, Compression Type: LZW. Note: if you change the output directory the cell size will revert to the default and you have to go back and change it to "1" again.

E. Create mosaic of georeferenced images

Create a mosaic of images to ensure that the best part of each image or photo is displayed.

Using Arc Catalog, create a file geodatabase if needed, call it "mosaics". Right-click the geodatabase and choose "New" then "Mosaic Dataset". Name it after the study area, photo type and date, e.g. "KOVApn50". Choose the Alaska Albers coordinate system (under Projected Coordinate systems, Continental, North America). Under "Pixel Properties", type the number of wavelength bands. The pixel type will usually be "8_BIT_UNSIGNED", for data that ranges from 0 to 255. Hit "OK". Using Arc Catalog, right-click the new mosaic and choose "Properties". Under "Defaults", make sure that "Always Clip the mosaic dataset to its Footprint" is set to "Yes".

Open the Add Rasters To Mosaic Dataset tool (Data Management Tools, Raster, Mosaic Dataset). Choose your raster mosaic and Raster Type: Raster Dataset, Input Data: Dataset. Using the folder tool under "Input Data", navigate to your folder and add the images. Under Advanced Options check Build Raster Pyramids and Calculate Statistics, then hit OK.

F. Create a new footprint layer.

F1. We need to create a new footprint layer that contains the part of each image that we want to use. This allows us to choose the best image in overlap areas. For satellite images, we mainly need to avoid cloudy or hazy areas. For aerial photographs, if possible we also want to use just the center of each photo and avoid the darker areas near the corners. With Arc Catalog, create a new polygon shapefile with Alaska Albers coordinate system, call it "*_footprints.shp", start editing, and create

the first polygon by digitizing four points that outline the desired part of the first image. Be sure snapping is enabled, select this polygon, display the neighboring image and use the "Auto Complete Polygon" Construction Tool under Create Features to digitize the next polygon; the resulting new polygon will snap to the previous one with no overlap. Continue until all footprints have been digitized. Be careful if you edit a vertex that is surrounded by polygons, because you will only move it for one polygon and create gaps or overlaps between polygons. If you need to move a vertex, be sure snapping is enabled and move the vertex of all the neighboring polygons to exactly the same place.

F2. Label the new footprint layer. Stop editing the footprint layer and open the attribute table. Add a new column to the footprint layer called "image", data type "text". Start editing again, and fill in the name of the image for each footprint polygon. Copy and paste the names from the ArcMap table of contents to avoid errors. The names should match the "Name" field in the attribute table of the auto-generated footprint layer of the mosaic created above. You may have to add or remove the file extension (*.tif) to facilitate this.

F3. Join the new footprints to the mosaic. Open the "Import Mosaic Dataset Geometry" geoprocessing tool (Data Management Tools, Raster, Mosaic Dataset). Choose the new mosaic. The "Target Feature Class" is "FOOTPRINT", the "Target Join Field" is "Name", the "Input Feature Class" is the new footprints shapefile, and the "Input Join Field" is "image". Hit OK. Open the "Build Boundary" geoprocessing tool (Data Management Tools, Raster, Mosaic Dataset), choose the mosaic, and hit "OK". You should see your mosaic now, but keep in mind that it may not display until you zoom in.

Standard Operating Procedure (SOP) # 2: Satellite Image Preparation

Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background To prepare satellite images for mapping water bodies they must be rectified and converted to panchromatic. In the future more accurate water body mapping may be made using the data from the available wavelength bands, but for comparison to panchromatic historical aerial photographs this protocol (Swanson 2017) currently uses only panchromatic data.

B. Rectification

Locate the individual images needed. If you are using a mosaic of many images created elsewhere (e.g., the NPS Regional Office), use the ArcMap identify tool to determine which images are needed. Add them to an ArcMap project. The image mosaic probably uses "on-the-fly" orthorectification, which means that individual images added to a project will not be orthorectified. If your newly added images register exactly over the original mosaic that they came from, they are already rectified and you can proceed to the next step. If not, run the "CreateOrthoCorrectedRasterDataset" geoprocessing tool (Data Management Tools, Raster, Raster Processing). Name the output raster by appending "*rect" onto the stem of the original file name, with a .tif extension. The "Orthorectification Type" is "DEM", and under "DEM Raster" navigate to the best available DEM for the area. Keep the Z Fact as 1 and Z Offset as 0. If the original data has pixel size finer than 1 m, in the "Save As" dialog box that appears chose Cell Size: 1, NoData as: 256 (default), Resample Type: Bilinear Interpolation, Name: the image name with "*.tif" changed to "*rect.tif", Format: TIFF, Compression Type: LZW.

C. Convert to Panchromatic

If you have access to original panchromatic data, this step is not necessary. If you have multispectral data that has been pan-sharpened, you can reconstruct the panchromatic data using the "Raster Calculator" (Spatial Analyst Tools, Map Algebra) to average the bands. To be comparable to panchromatic aerial photos we will use bands 1-blue, 2 - green, and 3-red. Our output will be an 8-bit unsigned integer (values ranging from 0 to 255). Add the bands individually to your ArcMap project so that they can be selected with the raster calculator, and compute the mean of the 3 bands. If the original data ran from 0 to 2047 (16-bit) you will have to divide by 8; if the original data runs up to 65536 (32 bit) you will have to divide by 255. Round the result to the nearest integer. For example, if "image.tif" has 16-bit data, the formula would be:

```
Int(("image.tif - Band_1" + "image.tif - Band_2" + "image.tif - Band_3") /  
3 / 8)
```

D. Footprints

Create a footprints shapefile for the images as described in SOP #1, step E. Keep in mind that a plot will be mapped using the image where its center is located, so make your footprint boundary at least 60 m from the edge of the image (so our 56-m radius plot won't run off the image used to map it).

Standard Operating Procedure (SOP) # 3: Plot Establishment and Ice-Wedge Polygon Center Digitizing
Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background

This SOP describes the method used to set up the random 1-ha plots used for monitoring ice-wedge degradation, and to digitize ice-wedge polygon centers using ArcGIS 10. Small water bodies will be mapped within these plots in subsequent SOPs. Plots have been established for study areas in KOVA and NOAT (Swanson 2016) and steps B and C below need not be repeated there. The exact set of plots used in any two-date comparison of ice-wedge degradation may vary slightly due to lack of imagery or cloud cover. We have established 400 random plots in these two study areas with the intention to actually sample 300. If a plot cannot be sampled, the next unused plot in the numerical sequence is used (step D below). Also, with better imagery available in the future, the ice-wedge polygon centers mapped in these plots as a part of Swanson (2016) may need to be edited (steps E and F below).

B. Create random plot center points

B1. Set up the constraining feature. The constraining feature class is an ecological subsection, possibly constrained by other features, such as the park boundary or boundary of available imagery. Later you will put the specified number of plots in the constraining feature. If the constraining feature is an ecological subsection, first select the one you want, then create a layer (right-click the item in the ArcGIS table of contents, choose Selection, Create Layer from Selected Features). Then, export the selection layer as a shapefile to get just that polygon (right-click the layer, then Data, Export Data). If the subsection extends beyond NPS boundaries, clip it to the NPS unit layer using the "Clip" geoprocessing tool (Analysis Tools, Extract). If the subsection has several polygons, run the Dissolve geoprocessing tool (Data Management Tools, Generalization) to make them one first (otherwise you will get a higher density of plots in the smaller polygons).

B2. Generate the plot center points. Use the "Create Random Points" geoprocessing tool (Data Management Tools, Feature Class). The output feature class should be a shapefile named after the location, e.g. "ahn_plot_cntrs1.shp". The Constraining Feature Class is the shapefile from the previous step. Under "Number of Points" leave it as "Long" and choose 400. Enter 112.84 m (twice the radius of the plots) under "Minimum Allowed Distance" to prevent plot overlap. Hit OK to run.

Note: plot overlap was allowed in Swanson (2016) but the analysis has since been re-run with overlapping plots omitted and additional random plots added to make the sample sizes the same.)

Plots generated with the proper minimum distances described above will not overlap, but new random plots added to an existing set may overlap existing plots. Overlapping plots can be located automatically with the "Point Distance" geoprocessing tool (Analysis Tools, Proximity). Both the "Input Feature" and "Near Feature" are the plot center point shapefile. The search radius is 112.84 m (twice the plot radius). Delete any new plots that overlap existing plots.

If these plots are being created to supplement a sample that was not large enough, merge it with the existing plot center point shapefile using the Merge geoprocessing tool (Data Management Tools, General).

B3. Create plot identifiers. Create a new field called "plotID" by opening the attribute table of the plot center point shapefile, choose "Add Field" from the dropdown menu in the upper left. The variable type is Short Integer. Next compute the plotID values by right-clicking on the column heading, and selecting "Field Calculator". The formula box should have "plotID=" above it, enter "FID + 1" in the formula box. The reason for this step is to make sure there isn't a plot numbered 0, because later we multiply these identifiers times a raster with water (1) and non-water (0), and a zero zone would be interpreted as "non-water". This step also allows us to add additional plots with unique ID numbers, using the "Field Calculator" and formula "FID + n + 1" where n is the previous highest plot ID number.

B4. Compute the point coordinates. Add two new fields to the attribute table "x_akalb83" and "y_akalb83" (double data type). Right-click and use "Calculate Geometry..." to add the coordinates.

B5. Join the names of best images for each plot. We will make a spatial join of the plot centers to the footprints shapefile to identify the best image to use from each time slice. Right-click on plot centers shapefile created above and choose "Joins and Relates". In the dialog box that appears, choose "Join data from another layer based on spatial location". Select the footprints shapefile created in SOP #1 as the layer to join, and select the button "it falls inside". Name the new layer "*_plot_cntrs2.shp" and run. Open the attribute table and delete the unneeded fields "FID_2", "Id", and "threshold". Right-click on the "image" field and choose "Properties", then edit the Alias to a unique name for the image source (e.g., ikonos08). Repeat for any other image sets and name the last one "*_plot_cntrs.shp". Delete the intermediate files *1.shp, *2.shp, etc..

C. Create 1-ha sample plots

Use the Buffer geoprocessing tool (Analysis Tools, Proximity) to create circular plots around each point. The "Input Feature" is the random points created in the previous step. Under Distance leave as "Linear unit" and enter 56.42 meters (the diameter of a 1 ha plot). Name the output *_plots.shp.

D. Mark the no-data plots

Flag the plots that are outside of photo coverage, cloudy, or otherwise not suitable. In the KOVA study area, we have also eliminated a few plots (4) that had extensive tree shadows that would be mistakenly mapped as water. The CID field on the plot shapefile table (*_plots.shp) isn't used for

anything now, and all values are currently "0". Edit to "1" on no-data plots. Check plots until you have 300 with good images from both dates, and record the highest plot number that you will need to sample. The easiest way to see if you have enough is to "Select by Attributes" with the criteria "CID" = 0 AND "plotID" < x where x is the highest plotID that you're proposing to use.

E. Digitize ice-wedge polygon centers:

Create a point shapefile to contain the ice-wedge polygon centers from a single study area (e.g. Lower Noatak Lowlands subsection). Name it "*iwpoly_cntrs.shp" and define its coordinate system as Alaska Albers (under Projected Coordinate Systems, Continental, North America).

Open the attribute table for the circular 1-ha plots. Select them sequentially starting at plotID = 1. Right-click and choose "Zoom to Selected". Adjust the zoom back out to 1:1,000. Digitize all visible polygon centers on any image date with a point. Digitize all of the polygon centers that are inside the plot, and the polygons surrounding the plot out to about 30 m from the plot boundary. (You need the latter because later we will calculate the distance from each water pixel in the plot to its nearest two polygon centers, and either of them could be just outside the plot.) Be sure that snapping is turned off. Select the next plot in the table, right-click, and select "Pan to" (this will keep the zoom level at 1:1,000).

When digitizing is complete, compute the point coordinates: add two new fields to the attribute table "x_akalb83" and "y_akalb83" (double data type). Right-click and use "Calculate Geometry..." to add the coordinates. Also, add the distance to the nearest plot center using the "Near" geoprocessing tool (Analysis Tools, Proximity).

You will probably want to complete SOP #4 Polygon "Ice-wedge polygon visual classification" before proceeding, because you may notice additional polygon centers that you will want to digitize during that step.

F. Create ice-wedge zones layer

In this step we use the ice-wedge polygon centers to create zones, within which we will map water-filled troughs and ponds. These small zones, which occupy only the parts of the plots that contain ice wedges, are called "ice-wedge zones". We create them using the ArcGIS "Aggregate Points" geoprocessing tool, which connects ice-wedge polygon centers closer than a chosen distance (30 m) and creates a map polygon from the outermost of these lines. This process was chosen because it can omit areas without ice-wedge polygons that are surrounded by ice-wedge polygons.

F1. Create ice-wedge zones from the ice-wedge polygon center points. Use the "Aggregate Points" tool under Cartography Tools, Generalization. The input feature is the ice-wedge polygon center points shapefile from the previous step. Name the output feature *_agg.shp. The "Aggregation Distance" is 30 m.

F2. Intersect the ice-wedge zones polygons with the sample plots. Use the Intersect geoprocessing tool (under "Analysis Tools", "Overlay"). The input features are the *_agg.shp file created in the previous step and the shapefile of the 1-ha circular plots (*_plots.shp). Name the output file *_int.shp and leave the defaults for the rest of the choices and run. Open the attribute table scan for any zones

that have a "1" under "CID" and delete them. Then delete all of the columns except FID, Shape, and plotID. These are plots we don't want to use because of poor imagery or plot overlap (see part D above).

F3. Dissolve multiple zone polygons in a plot. Occasionally there will be more than one polygon created in a plot by the previous step. We want these to be aggregated for area calculations and later for appending into the database. Use the Dissolve geoprocessing tool (under Data Management Tools, Generalization). The "Input Features" is *_int.shp from above and the "Output Feature Class" is "*_iwzones.shp". The "Dissolve Field" is "plotID". Be sure the "Create multipart features" box is checked.

F4. Compute the area of each ice-wedge zone. Add a new field to *_iwzones.shp named "area_msq", data type "Double". Right-click on the new field and choose "Calculate Geometry" to compute the area in square meters.

F5. Choose an image for mapping each ice-wedge zone. In this step we deal with the fact that our images usually overlap, so that each ice-wedge zone could be mapped multiple times with different results. Add text fields to the attribute table of the ice-wedge zones shapefile named after each image year or type (e.g. "IKONOS06"). Next we will join to the plot centers shapefile, where we have already identified the best image to use for each plot. Right-click *_iwzones.shp and choose "Joins and Relates", "Join". In the dialog box that appears, choose "Join Attributes from a Table". The join will be based on the field "plotID". Under "Choose the table to join to this layer", choose the plot centers shapefile created in step B above, which should have columns for each image set being analyzed. Open the attribute table of the result and right-click one of the columns you just created to store the best image data in. Copy the data from the join column that contains the image names for that image set by right-clicking and choosing "Field Calculator". In the dialog box that appears, double-click the column joined in from the plot centers shapefile that contains the names that belong in the column you selected, and hit OK. Repeat for the other image column(s) created at the beginning of this step. Now you can choose "Joins and Relates" at the top of the table again and then "Remove Joins" and your image names will persist in the ice-wedge zones shapefile. Caution: sometimes file extensions get lost in the processing. Be sure that these file names all have their ".tif" extensions.

Standard Operating Procedure (SOP) # 4: Ice-wedge polygon visual classification

Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background

In addition to quantitative analysis of the area and position of water on the plot, we also subjectively evaluate the morphology of ice-wedge polygons on each 1-ha plot. In each plot we classify the form of the polygons if present and note the presence or absence of water-filled troughs or pits.

B. Data entry form

Data can be entered into a spreadsheet with a row for each plot and columns for each image date. They may also be entered into the plot centers shapefile attribute table.

C. Classify polygons

Pan to each plot at a scale of 1:1000 in numeric order, as described in SOP #3 above. This may be done at the same time as the ice-wedge polygon centers are digitized (SOP #3). Check all the photo dates that you are sampling.

Two digits are entered for each image date, the first for the polygon center and the second for the polygon troughs. The first digit (polygon centers) is:

0 – None. No polygons are visible in the plot. No second digit (trough class) is entered.

1 – Low center. More than two-thirds of the polygons have dark centers resulting from wetness. Low-center polygons often have narrow wet troughs on their margins also, but a dryer ridge is apparent between the center and the trough. Be aware that occasionally the centers of dry, distinctly high-center polygons can be slightly darker than the margins due to sparse dwarf shrub vegetation in the centers contrasting with bright graminoid vegetation in the moister troughs (Fig. 12).

2 – Mixed. Polygons are visible but of mixed type such that neither (1) or (3) applies.

3 – High center. More than two-thirds of the polygons have light-colored centers, indicating high-center or flat polygons, with narrow wet troughs. See the note under low-center polygons about high-center polygons with dark centers (Fig. 14).

The second digit (polygon troughs) is:

0 – troughs lack standing water. Ponds may be present in polygon centers

1 – water-filled troughs or pits are present along trough margins.

Enter -99 for "no data" for any plots that could not be sampled due to lack of imagery, clouds, or other reasons.

Standard Operating Procedure (SOP) # 5: Ice-wedge polygon water-filled trough and pit mapping
Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background

The pixels representing water-filled troughs and ponds are mapped by "thresholding" the image: assigning a class of "water" to all pixels darker than some chosen level. For panchromatic aerial photographs the single wave band is used for thresholding. For consistency we also use a panchromatic satellite image band. In the future if infrared data are available at 1-m resolution or better, we may choose other bands or band combinations. The threshold level is set manually for each image and used to re-classify all pixels into water and non-water. Then the ice-wedge zones created in the previous SOP are used to extract for analysis just the water within ice-wedge polygon portions of the sample plots. This avoids mapping water bodies of other origins, such as a large lake that might intersect a sample plot.

B. Choose the threshold levels for each input image

Place the rectified images that will be used to map water in an ArcGIS project above the mosaic created previously from these images. Adjust the layer properties of the individual images, the "Symbology" tab, to "Classified" with 2 classes, which should display as black and white. Adjust the breakpoint between the two classes and turn the layer on and off (to view the original image) until a breakpoint has been selected that correctly maps as much water as possible. Adjust the display of the classified image so that low values (water) are red and high values (land) are no color. Don't worry about gaps caused by glare from large lakes; concentrate on small water bodies in the portion of the photo that was used in the mosaic (display the footprints shapefile that was used to create the mosaic so you can see the boundaries). Record the result in the attribute table for the footprints shapefile; you will first need to add a field "threshold", data type short integer. Adjacent photos on a line should have the same or similar thresholds.

If you have a line of air photos with similar properties you can set the display of a group at once to save time. After checking the threshold value for several of the photos, set the symbology of the rest using the "Apply Symbology From Layer" geoprocessing tool (Data Management Tools, Layers and Table Views). Run in batch mode to set the display for your whole line of photos. You can also import the settings one at a time by changing the symbology to "Classified" and then import the

settings from the previous photo (click the folder icon next to "Draw raster grouping values into classes"). Edit the break values if needed.

C. Prepare the main text file for the script

Export the footprints shapefile(s) attribute table(s) to a comma-delimited text file. This is done by opening the attribute table, clicking on the table icon in the far upper-left corner, and choosing "Export". In the "Export Data" dialog box, be sure it says "Export: All Records". Under "Output table:" click on the folder icon and edit the file name, and change "Save as type:" to "text file". Repeat for other image sets.

Open in your spreadsheet first and delete all of the columns except "image" and "threshold". Also delete the header row. Check to make sure the image names match the names as used in the directory of images that will be thresholded to map water (sometimes the ".tif" extension may be missing). This file will become the main input file for the script used in next step.

D. Run the water mapping script

The Python script "IWpolysThresholdMask.py" executes the steps necessary to map water in the ice-wedge zones for one set of images.

```
#This script iterates through a list of images and completes the
following:
# 1) Selects records from the ice-wedge zone shapefile that go with the
current photo (to avoid mapping the same area twice with overlapping
photos).
# 2) Converts the ice-wedge zone polygons to a raster.
# 3) reclassifies each panchromatic image to water (1) vs. non-water (0).
# 4) Multiplies the ice-wedge zone raster times the water map of the photo
to obtain a raster with water in the ice-wedge zones labeled with the zone
ID number, non-water in the ice-wedge zones labeled "0", and all areas
outside the zones labeled as "no data".
# 5) Creates points in a shapefile for all the pixel centers from the
previous step.
# 6) Deletes all points labeled "0" (non-water).
# 7) When all the images in infile.txt have been processed, merges all the
resulting point shapefiles into one file.

# User edits here

#all the images to be analyzed are in this directory
inpath = "C:\\GIS\\GISdataNoBackup\\IKONOS\\NOAT_IK_pan\\"

#results go here
outpath = "C:\\GIS\\GISdata\\IWPolygons\\NOAT_IK\\water\\"

#text file contains a list of images and their threshold values, comma-
delimited, with a header row
intxtfile = "C:\\GIS\\GISdata\\IWPolygons\\NOAT_plots\\infile_lnlk.csv"

#path and filename of shapefile containing iw zones (portions of plots
with ice-wedge polygons)
zonefile = "C:\\GIS\\GISdata\\IWPolygons\\NOAT_plots\\lnl_iwzones.shp"
```

```

#the column name in the ice-wedge zone shapefile that contains the name of
the image used to map each zone
image_col_name = "ikonos06"

# End of user edit section-----

# Import system modules
import arcpy
from arcpy import env
from arcpy.sa import *
env.workspace = outpath
env.overwriteOutput = True

# Check out the ArcGIS Spatial Analyst extension license
arcpy.CheckOutExtension("spatial")

# Read input and output file names from infile.txt
infilelist = open(intxtfile, 'r')
mergelist = [] #initialize list of output water shapefiles to use in
merge command
for linex in infilelist:
    line = linex.replace("\n", "") #delete the newline character
    items = line.split(',') #split the line into a list of items
    infile = items[0] #first item is the input file name
    thresh = int(items[1]) #second item is the threshold value
    outshape = infile[:-4]+"watpts.shp" #shapefile to hold centers of
water pixels

    print infile #to track progress

    #select records in iw zone shapefile that go with the current photo
    arcpy.MakeFeatureLayer_management(zonefile, "lyr")
    expression = "\"" + image_col_name + "\" =" + "\"" + infile + "\""
    #must double quote column, single quote data
    arcpy.SelectLayerByAttribute_management("lyr", "NEW_SELECTION",
expression)
    rec_count = arcpy.GetCount_management("lyr") #check if selection is
empty
    if int(rec_count.getOutput(0)) > 0: #continue only if there are iw
zones on that photo
        #add shapefile name to list that will be used to merge all at the
end
        mergelist.append(outshape)
        #reclassify photo to water vs. not
        reclass = Reclassify(inpath+infile, "Value",
ReclassByTable([[0,thresh,1],[thresh+1,255,0]]))
        #next make a raster out of the zones for the one photo
        arcpy.FeatureToRaster_conversion("lyr", "plotID", "tmpzones", "1")
        #multiply those zones times the water raster to get just the iw-
polygon water
        waterpixels = reclass * "tmpzones"
        #make shapefile of points at centers of water pixels
        arcpy.RasterToPoint_conversion(waterpixels, outshape, "VALUE")
        #select the points with value of zero, which are non-water inside
the iw-polygon zones, and delete
        arcpy.MakeFeatureLayer_management(outshape, "templayer")

```

```

        arcpy.SelectLayerByAttribute_management("templayer",
        "NEW_SELECTION", '"GRID_CODE" = 0')
        arcpy.DeleteRows_management("templayer")

infilelist.close()

#merge all water point files
arcpy.Merge_management(mergelist, "allwatpt.shp")

#delete intermediate files
arcpy.Delete_management(outpath+"tmpzones")
arcpy.Delete_management(outpath+"times_ras")

```

D1. Prepare the inputs. To run the script, edit the variables at the top of the script. Make sure all of the rectified images are in one directory (the "inpath"). Be sure to double-slash "\\" between directory levels and at the end. Create a subdirectory called "water" where the results will go and copy that path into "outpath". The "intxtfile" is the list of images and threshold values created in the previous step. The "plotfile" is the path and filename for the ice-wedge zones shapefile, which contains the boundaries of the areas to analyze. Finally, edit the variable "image_col_name" to match the name of the column in created in step E4 of the previous SOP#3, which contains the name of the image that will be used to map each zone.

D2. Run the script. The script iterates through the list of images created in the previous step and then completes the following operations: 1) selects records from the ice-wedge zone shapefile that go with the current photo (to avoid mapping the same area twice with overlapping photos). 2) Converts the ice-wedge zones to a raster. 3) Reclassifies each panchromatic image to water (1) vs. non-water (0). 4) Multiplies the ice-wedge zone raster times the water map of the photo to obtain a raster with water in the ice-wedge zones labeled with the zone ID number, non-water in the ice-wedge zones labeled "0", and all areas outside the zones labeled as "no data". 5) Creates points in a shapefile for all the pixel centers from the previous step. 6) Deletes all points labeled "0" (non-water). 7) Merges all the resulting point shapefiles into one file. The result is a point shapefile "allwatpt.shp" with each point representing the center of a 1 m² pixel of water, and each point is labeled with one plot number.

E. Find the two nearest ice-wedge polygon centers to each water pixel point

To determine if a water pixel is positioned near a polygon center or along a trough, we find the distance of each water pixel to the two closest polygon centers. Later we will use these two distances to compute the distance index $2a/(a + b)$, where a is the distance to the closest ice-wedge polygon center and b is the distance to the 2nd closest ice-wedge polygon center. This index ranges from 0 at the polygon center to 1 along polygon boundaries.

Run the "Generate Near Table" geoprocessing tool (Analysis Tools, Proximity). The "Input Feature" is the shapefile of water pixel center points from the previous step. The "Near Features" is the ice-wedge-polygon center point shapefile. Name the Output Table after the study area and image type, ending with "nr.dbf" (for easy database import, keep the file name to 8 characters or less). The "Search radius" is 30 m. Leave the "Location", "Angle", and "Find only closest feature" boxes

unchecked. Set the "Maximum number of closest matches" = 2. Repeat for the second image set if you have one.

Standard Operating Procedure (SOP) # 6: Data Analysis and Reporting Version 1.0 (Feb 2017)

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

A. Background

Data from this project is stored in Microsoft SQL Server INPYUGAMS08SQL\NUNA, database name ARCN_Permafrost. For definitions of the tables, columns, and queries in this database, see the "metadata" tables in the database. The queries shown below can be saved in an Access database connected to ARCN_Permafrost by the following odbc connection script (edit the UID as needed):

```
[ODBC]
DRIVER=SQL Server Native Client 10.0
UID=DKSwanson
DATABASE=ARCN_Permafrost
WSID=INPYUGA22311
APP=Microsoft Office 2010
Trusted_Connection=Yes
SERVER=INPYUGAMS08SQL\NUNA
```

Copy to a text file and save as "arcn_permafrost_nuna.dsn". Now create an Access database and under the "External Data" tab select "ODBC Database". Choose to link to the data source by creating a linked table (do not import the data), and navigate to the "arcn_permafrost_nuna.dsn" file and select it, then "OK". Highlight all the "dbo.*" (database objects) plus the tables INFORMATION_SCHEMA_COLUMNS and INFORMATION_SCHEMA_TABLES. This database now gives you access to the master database while allowing you to store temporary tables and queries.

B. Import data

B1. Plot centerpoint location data. Import the "*.dbf" table of the ice wedge plot centers shapefile (you will probably have to copy and rename it with less than 8 characters). Append new records to the database table "ice_wedge_plots" only if you have added new plots. Append the plotID and coordinates, with the appropriate study area identifier. We store the plot identifiers ("plotID") and the Alaska Albers NAD 83 coordinates of the plot centers.

B2. Add image identifiers. Do a join between the table imported in step B1 and the table "ice_wedge_plots" on study area and plot id. Then with an update query use the photo identifiers in the imported table to populate the image id columns (img1, img2, img3 etc.). Currently "img1"

contains identifiers for the c. 1950 panchromatic aerial photos, and "img2" contains identifiers for the 2006-2009 IKONOS images. If you place image identifiers in columns img3 or img4, describe the images used in the appropriate record of table "metadata_columns".

B3. Polygon classification data. Import the spreadsheet of polygon classes into the database. Join to the "ice_wedge_plots" table on study area and plotID. Then with an update query populate the columns iw_img1, iw_img2, iw_img3, etc. with the corresponding wedge assessment data for that image date.

B4. Ice-wedge zone data. If you have edited or digitized new ice-wedge polygon centers, you will need to replace the ice-wedge zone data for that study area and import the new data (created in SOP #3 above). Import the attribute table of "*iw_zones.shp" and append to the database table "ice_wedge_zones", adding the appropriate study area identifier. The plot numbers are in the column "plotID" and the areas of ice-wedge zones are in column "area_msq".

B5. Ice-wedge polygon centers. If you have edited or digitized new ice-wedge polygon centers, you will need to import them and replace the existing data. Open the attribute table for the ice-wedge polygon center point shapefile, export it as text, and import it into the database. Don't try to import the dbf of the shapefile directly into your database, because it lacks the field "FID". Give the imported table a temporary name like "ahn_polyctr". Append it to the database table "iw_poly_centers" with an append query that inserts the appropriate study area ("AHN", "LNL", or "BELA"). The import column "FID" appends to the database column "iwctrID", and the x-y coordinates append to their respective columns.

B6. Water points. Open the attribute table for the water points shapefile "*wat.shp" produced in SOP #5 above, and export it as text (don't try to import the attribute table dbf file directly, because it is missing the FID column that we need to link to the "near table" in the next step). Import it into the database. Append it to the database table "water_pts" with an append query that inserts the appropriate study area ("AHN", "LNL", or "BELA") and image group (for example, "pan50" for 1950s panchromatic aerial photos), appends FID to the target table columns of the same name, and column "GRID_CODE" to "plotID". The column "POINTID" is not appended.

```
INSERT INTO water_pts (study_area, image_group, FID, plotID )
SELECT "LNL" AS study_area, "pan50" AS image_group, FID, GRID_CODE
FROM TMPInlpnwat;
```

Repeat for a second image set if you have one

B7. Water points "near polygon" distance information. Import the table created by the "Generate Near Table" geoprocessing tool in SOP #5 above into the database and temporarily name it something like "ahn_near_pts_pan50". Append it to the database table "water_near_pts" with an append query that inserts the appropriate study area ("AHN", "LNL", or "BELA") and image group (for example, "pan50" for 1950s panchromatic aerial photos). The column "OID_" is not appended.

```
INSERT INTO water_near_pts (study_area, IN_FID, image_group, NEAR_FID,
NEAR_DIST)
```

```
SELECT "AHN" AS study_area, "pan50" AS image_group, IN_FID, NEAR_FID,
NEAR_DIST
FROM ahn_near_pts_pan50;
```

Repeat for a second image set if you have one

C. Compute the distance index

Use a group summary query to find the minimum and maximum value for NEAR_DIST (distance to ice-wedge polygon centers) of each IN_FID point in "water_near_pts". Since the table contains only distances to the two closest ice-wedge polygon centers, these will actually be the distances to the closest and second closest polygon centers. Then, we compute the distance index $2a/(a+b)$, where a and b are the distances to the nearest and second nearest ice-wedge polygon centers, respectively. We typically compute the indices only for one study area at a time (hence the HAVING study_area="LNL"; statement; enter the appropriate study area code here). Save the query as "compute_index".

```
SELECT water_pts.study_area, water_pts.image_group, water_pts.plotID,
water_near_pts.IN_FID,
2*Min([NEAR_DIST])/(Min([NEAR_DIST])+Max([NEAR_DIST])) AS [index]
FROM water_pts INNER JOIN water_near_pts ON
(water_pts.FID = water_near_pts.IN_FID) AND
(water_pts.image_group = water_near_pts.image_group) AND
(water_pts.study_area = water_near_pts.study_area)
GROUP BY water_pts.study_area, water_pts.image_group, water_pts.plotID,
water_near_pts.IN_FID
HAVING water_pts.study_area="LNL";
```

The "near" table has a field IN_FID which matches the FID of "water_pts". We will join these two tables using IN_FID and FID in the next query, so that we can link the plot numbers to the water point distance measurements NEAR_DIST.

D. Summarize Water Pixel Properties

D1. Compute area of the ice-wedge zones. Sum the area of ice-wedge zones in the study area with a summary query, saved as "iw_zone_areas":

```
SELECT study_area, Sum(iw_area_msq) AS SumOfiw_area_msq, Count(plotID) AS
CountOfplotID
FROM ice_wedge_zones
GROUP BY study_area
HAVING study_area="LNL";
```

D2 Create histograms of distance indices. The land area that falls within a certain distance index of a polygon center is roughly proportional to the square of the index. For example, all pixels with an index of about 0.5 or less should cover about a quarter of the area, not half. Distance indices computed for ten thousand random points in the Ahnewetut Wetlands and Lower Noatak Lowlands ice-wedge zones showed that indices of 0.56, 0.75, and 0.89 separate the quartiles of this distribution, i.e., one quarter of all possible locations have an index of 0 to 0.56, one quarter have an index of 0.56 to 0.75, etc. The following query takes the results of the query "compute_index" and breaks the distance indices of all water pixels into these four bins (the "sectors" of Fig. 18) that can be used to

plot a bar graph. The column "index_bin" names the 4 bins while "CountOfWaterPx" gives the count of water pixels (equivalent to square meters since pixels are 1 square meter). Save this as "water_index_bins".

```
SELECT study_area, image_group,
IIf([index]<0.56,1,IIf([index]<0.75,2,IIf([index]<0.89,3,4))) AS
index_bin, Count(index) AS CountOfWaterPx
FROM compute_index
GROUP BY study_area, image_group,
IIf([index]<0.56,1,IIf([index]<0.75,2,IIf([index]<0.89,3,4))) ;
```

A crosstab of the result will produce a more familiar output, with a column for each of the 4 bins:

```
TRANSFORM First(CountOfWaterPx) AS FirstOfCountOfWaterPx
SELECT study_area, image_group
FROM water_index_bins
GROUP BY study_area, image_group
PIVOT index_bin;
```

Save this as "water_index_xtab". The results will look like this:

study_area	image_group	1	2	3	4
AHN	ik08	379	479	841	1114
AHN	pan50	1028	785	658	497

The numbers 1, 2, 3, and 4 are the four sectors, from the center (1) to the margin (4). Copy the result into a spreadsheet, starting at row B1 as shown below. Compute the sum of water pixels for each image group (in cells H2 and H3) and normalize each value to a proportion of the water area, as shown in the rows 5 and 6. As shown in rows 8 and 9, compute the percent cover by water in each quarter sector by dividing the number of water pixels (1 square meter each) times 100 by the area of the ice-wedge zones (obtained from the previous step and typed into cell A9; in this example 238954.4 m²), divided by 4 (since each sector represents one-fourth of the area).

	A	B	C	D	E	F	G	H
1	Summary	study area	image group	1	2	3	4	total
2	Water, m ²	AHN	ik08	379	479	841	1114	=SUM(D2:G2)
3		AHN	pan50	1028	785	658	497	=SUM(D3:G3)
4								
5	Proportion	AHN	ik08	=D2/\$H2	=E2/\$H2	=F2/\$H2	=G2/\$H2	=H2/\$H2
6	of water area	AHN	pan50	=D3/\$H3	=E3/\$H3	=F3/\$H3	=G3/\$H3	=H3/\$H3
7								
8	% of area	AHN	ik08	=100*D2/(\$A\$9/4)	=100*E2/(\$A\$9/4)	=100*F2/(\$A\$9/4)	=100*G2/(\$A\$9/4)	=100*H2/\$A\$9
9	238954.5	AHN	pan50	=100*D3/(\$A\$9/4)	=100*E3/(\$A\$9/4)	=100*F3/(\$A\$9/4)	=100*G3/(\$A\$9/4)	=100*H3/\$A\$9

The computation results from the above spreadsheet are:

	A	B	C	D	E	F	G	H
1	Summary	study area	Image group	1	2	3	4	total
2	Water, m ²	AHN	ikonos	379	479	841	1114	2813
3		AHN	pan50	1028	785	658	497	2968
4								
5	Proportion	AHN	ikonos	0.13	0.17	0.30	0.40	1.00
6	of water area	AHN	pan50	0.35	0.26	0.22	0.17	1.00
7								
8	% of area	AHN	ikonos	0.63	0.80	1.41	1.86	1.18
9	238954.5	AHN	pan50	1.72	1.31	1.10	0.83	1.24

Plot bar graphs to illustrate the different amounts of water in the four sectors (Fig. 19). If water were distributed randomly over the landscape, the proportion of the water area (rows 5 and 6) would be 0.25 in all 4 sectors. A proportion greater than 0.25 in bin 1 (the polygon centers) suggests numerous low-center polygons with central ponds, while proportions greater than 0.25 in bins 3 and 4 indicate ice-wedge marginal pits. The absolute areas of water in the various sectors (rows 7 and 8) is useful in determining whether the observed changes are due to thermokarst or other factors such as seasonal wetness changes or choice of the mapping threshold. If the absolute area of water mapped decreased in sector 1 while increasing in sectors 3 and 4 (as in the example), it would be difficult to argue that the result is due exclusively to the overall wetness or dryness of one date versus the other.

D3. Create an export table for R. Further analysis requires computation of medians and statistical tests that are performed in R statistical software. You could export the entire contents of the "compute_index" query above and subset the data in R, though it will probably be easier to subset a study area and the two years to be compared first:

```
SELECT study_area, image_group, plotID, index
FROM compute_index
WHERE study_area="AHN";
```

For convenience you can simply select the query output table and copy/paste it to a text file "Rinput.txt", rather than work through the export routine.

D4. Compute summary statistics in R

D4.1. Start R and import the table created in the previous section using this code, after editing the path and file name in the "read.table" command:

```
dataset <- read.table("O:/Monitoring/Vital
Signs/Permafrost/Results/IWpolygons/Rinput.txt", header=TRUE, sep="\t",
na.strings="NA", dec=".", strip.white=TRUE)
```

D4.2. Compute the count of water pixels and their median distance index by image group (i.e. sample year). Load the doBy package and run this code:

```
library(doBy)
fn1 = function(x) {c(md = median(x), n = length(x))}
summaryBy(index ~ image_group, data = dataset, FUN = fn1)
```

The output will look like this:

```
image_group index.md index.n
1 ikonos 0.8518150 2813
2 pan50 0.6756483 2968
```

The median index and count of pixels are in the 2nd and 3rd columns. A median distance index greater than 0.75 (the boundary between sectors 2 and 3) indicates that the majority of the water pixels occur along the margins of the ice-wedge polygons, as opposed to their centers.

D4.3. Run a Wilcoxon rank-sum test for the difference in distance index between the two image years. Since the data are clustered by plot (i.e. within-plot indices are not independent), we will use the Wilcoxon rank-sum test available in the R package "survey", which adjusts for clustering in the data (Lumley and Scott 2013; Lumley 2016). Load the "survey" package and define the survey design. In our case, the only design element is "plotID" as a clustering variable. The design is saved as variable "des1":

```
library(survey)
des1 <- svydesign(id = ~plotID, data = dataset)
```

Now run the Wilcoxon test. The first variable ("index ~ image_group") is the formula, which indicates that we will compare "index" for different "image_groups". The second variable ("des1") calls the design specified above:

```
svyranktest(index~image_group, des1, test = "wilcoxon")
```

The results will look like this:

```
data: index ~ image_group
t = -4.2077, df = 49, p-value = 0.0001095
alternative hypothesis: true difference in mean rank score is not equal to
0
sample estimates:
difference in mean rank score
-0.1932138
```

The p-value is the probability that the two groups of distance indices came from the same population. In this case, the low p-value indicates that they did not.

F. Compute Proportion of Polygons with Marginal Ponds

F1. This analysis answers the question "what proportion of the ice-wedge polygons have marginal ponds?" It uses a series of queries to count the ice-wedge polygons with at least 5 m² of water in their outer two quarter-sectors.

F2. The first query, "center_anal1", joins the distance indices (in table "compute_index" from step C above) to the table "water_near_pts", which contains 2 records for each water point: its nearest and 2nd nearest polygon center ID. This step is needed because each water pixel at a polygon boundary

must be assigned to both of its nearby polygon centers. The query also selects out only water in the outer two quarter-sectors (index greater than 0.75).

```
SELECT water_near_pts.study_area, water_near_pts.image_group,
water_near_pts.IN_FID, water_near_pts.NEAR_FID, compute_index.index
FROM water_near_pts INNER JOIN compute_index ON (water_near_pts.IN_FID =
compute_index.IN_FID) AND (water_near_pts.image_group =
compute_index.image_group) AND (water_near_pts.study_area =
compute_index.study_area)
WHERE compute_index.index>0.75;
```

The next query (center_anal2) takes the result of the previous one, groups by the study area, image group, and polygon center identifier (NEAR_FID) to count of the number of 1 m² water pixels linked to each center. Then it passes on only those with more than 4 (i.e. 5 m² or more of water). It also joins in the table "iw_poly_centers" and screens out those ice-wedge polygons that are more than 46.42 m from the plot center (i.e. less than 10 m from the plot edge). This keeps us from counting plot-edge polygons where the marginal water wasn't mapped because it was outside of the plot.

```
SELECT center_anal1.study_area, center_anal1.image_group,
center_anal1.NEAR_FID, Count(center_anal1.IN_FID) AS CountOfIN_FID,
iw_poly_centers.plot_cntr_dist_m
FROM center_anal1 INNER JOIN iw_poly_centers ON
(iw_poly_centers.study_area = center_anal1.study_area) AND
(center_anal1.NEAR_FID = iw_poly_centers.iwcntrID)
GROUP BY center_anal1.study_area, center_anal1.image_group,
center_anal1.NEAR_FID, iw_poly_centers.plot_cntr_dist_m
HAVING (((Count(center_anal1.IN_FID))>4) AND
((iw_poly_centers.plot_cntr_dist_m)<46.42));
```

Finally, query "center_anal3" takes the results of the previous query and counts of the number of polygon centers that met the "more than 5 m² of water" criterion above.

```
SELECT study_area, image_group, Count(NEAR_FID) AS CountOfNEAR_FID
FROM center_anal2
GROUP BY study_area, image_group;
```

Divide these numbers by the count of polygon centers inside the plots in each study area to get the proportion of "degraded" polygons. Since we used only ice-wedge polygons more than 10 m from the plot edge, this is:

```
SELECT study_area, Count(iwcntrID) AS CountOfiwcntrID
FROM iw_poly_centers
WHERE (((plot_cntr_dist_m)<46.42))
GROUP BY study_area;
```

G. Summary of Visual Assessment

G1. Here we will analyze the classification of polygon terrain on each plot by visual assessment (SOP #4). Recall that the visual assessments include both a polygon classification (low-center: 1, mixed: 2, high-center: 3) and an assessment of the presence (1) or absence (0) of water filled, ice-wedge marginal pits.

G2. Run a simple summary query to count the number of plots with each polygon type and with or without marginal ponds (query "wedge_assessment_summary"):

```
SELECT study_area, iw_img1, Count(plotID) AS CountOfplotID
FROM ice_wedge_plots
GROUP BY study_area, iw_img2;
```

Run again for the ice wedge assessment of the other image year (e.g., iw_img2) and compare the two years for changes in polygon type and frequency of marginal ponds.

Section D Literature Cited

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Lumley, T. 2016. *Survey: Analysis of Complex Survey Samples*. (version 3.31). R Package.
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Lumley, T., and A. J. Scott. 2013. "Two-Sample Rank Tests under Complex Sampling." *Biometrika* 100 (4): 831–42. doi:10.1093/biomet/ast027.

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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