IP3 LiDAR collaborative research data report

Submitted to :

The IP3 research network.
c/o Dr John Pomeroy and Dr Julie Friddell
Kirk Hall, 117 Science Place
Centre for Hydrology
University of Saskatchewan
Saskatoon, SK S7N 5C8

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Prepared by:

Dr. Chris Hopkinson,
Research Scientist,
&
Allyson Fox,
Research Associate,
Applied Geomatics Research Group
Centre of Geographic Sciences
NSCC Annapolis Valley Campus
50 Elliott Rd,
RR1 Lawrencetown,
NS B0S 1M0

Email: chris.hopkinson@nscc.ca
Tel: 902 825 5424
Fax: 902 825 5479

A note on C-CLEAR research collaboration:

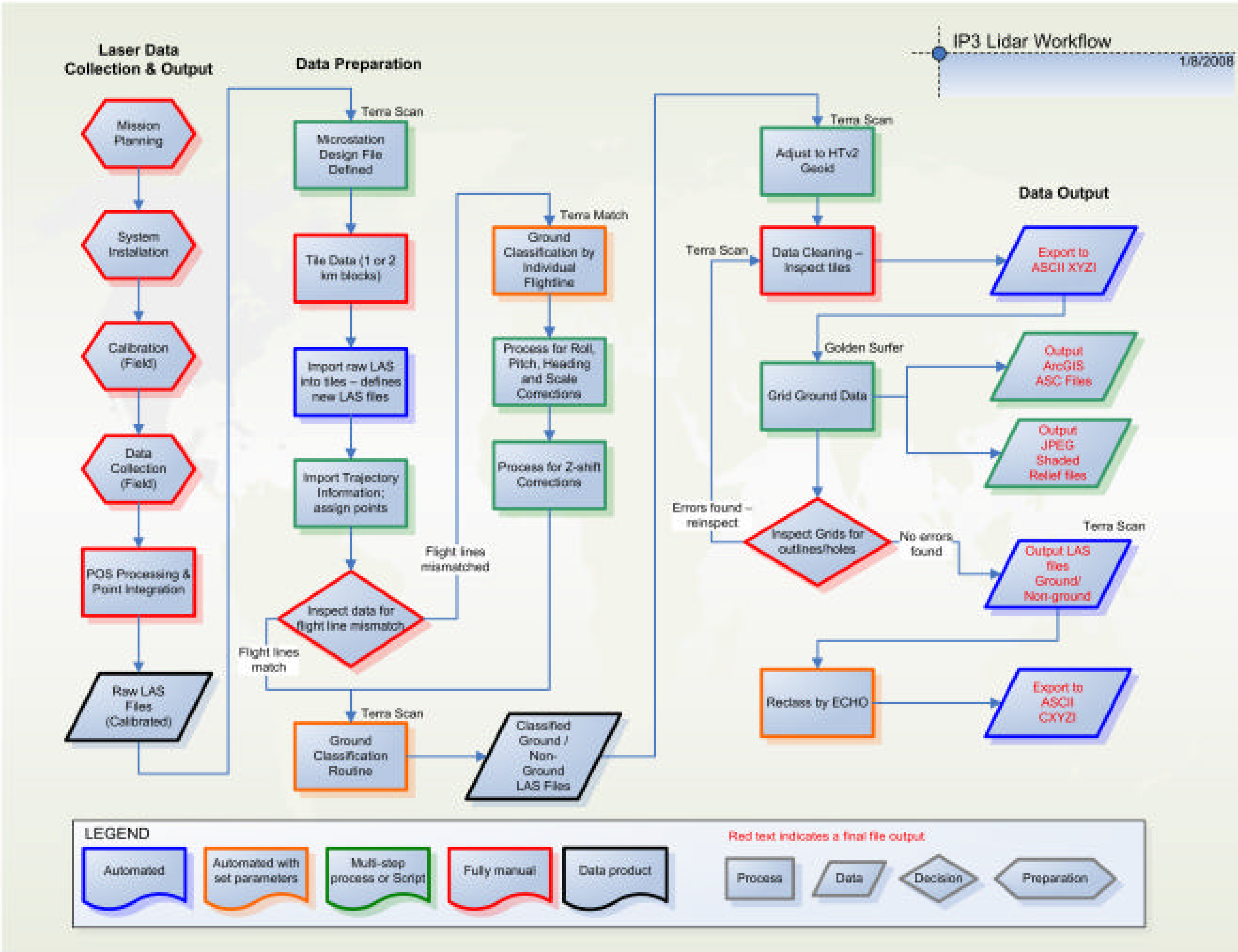
The ALTM used for this study, was acquired under a 2 million dollar CFI grant awarded to the AGRG (Drs Maher and Hopkinson) to support both AGRG research and to develop a national research consortium through C-CLEAR (The Canadian Consortium for LiDAR Environmental Applications Research). As such, we are able to provide these lidar research support services on a non profit basis, thus allowing our research partners to access lidar data at a fraction of the commercial cost (typically 5% to 20%). We respectfully request that our research collaborators understand the significant effort that goes into building and maintaining this consortium effort for the benefit of the Canadian research community. And further, to appreciate the time commitment involved in the mission planning, data collection and data processing; not to mention assistance with the development of research questions.

We are not a service provider and do not compete with the lidar industry. We are also not a charity. Our motivation, like all academics, is to do research and to educate. As such, we expect that supporting these collaborative research initiatives will result in co-authorship on journal publications. After all, like all academics, we must compete for funding, and if our time is spent on supporting the research of others, this takes time away from our own independent research activities. If these efforts do not result in publications for the AGRG staff supporting them, then we appear to be academically unproductive and this reduces our ability to continue to support the research community.

Thank you for the opportunity to assist you and be involved in your lidar research activities.

Enjoy ☺

The data collection and processing workflow:



Workflow diagram for IP3 Lidar Data Collection and Processing (prepared by Allyson Fox)

LiDAR data collection details:

Date: 4th August to 22nd August, 2007

Study Site	ALTM sensor	PRF kHz	Altitude (m a.g.l.)	Scan rate (Hz)	Scan angle (deg.)	Approx. points per m^2
Sibbald Creek	3100	50	1000	39	±23º	> 2
Marmot Creek	3100	33	500-2000	21	±23º	>1
Wolf Creek	3100	33	1350-1500	20	±23º	>1
Scotty Creek	3100	33	550-650	38	±20º	>1
Baker Creek	3100EA	70	1200	34	±25º	>1

Table 1. Lidar survey parameters IP3 study areas.

Sibbald Creek – JD 217
Marmot Creek – JD 219
Wolf Creek – JD 223
Scotty Creek – JD 227
Baker Creek – JD 234

A total of 139 survey flight lines were flown over the previously defined five study site polygons using the lidar survey specifications noted in Table 1. Airborne operations were coordinated and performed by Dr. Chris Hopkinson, Laura Chasmer and Allyson Fox, of the Applied Geomatics Research Group. The airborne data collection and calibration took over 70 hours and was performed out of the Calgary, Whitehorse, Fort Simpson, and Yellowknife airports.

Three calibration flights to bore sight align the Airborne Laser Terrain Mapper (ALTM) system components was performed over previously surveyed runway and hangar building control targets at Airdrie Airport prior to and following the main survey campaign. AGRG research staff under the supervision of Dr Hopkinson performed the necessary ground control surveys prior to airborne acquisitions. The flights were performed out of Calgary, Alberta.

GPS data collection:

During each survey flight, GPS base station data were collected by AGRG research personnel. Marmot and Sibbald used the same base station location at the Kananaskis research station. In the case of Wolf Creek and Scotty Creek, supplementary base station data were collected by the respective IP3 research teams. For Wolf Creek and Baker Creek, the Whitehorse and Yellowknife permanent CACS GPS data that are collected by the federal govt were used. The AGRG base station was a Leica SR530 dual frequency survey grade GPS receiver. For Marmot, Wolf Creek and Scotty Creek, AGRG research personnel also collected ground validation GPS data over ski hill (Nakiska) or highway surfaces using a second Leica SR530 rover unit.

All GPS base data used for airborne survey control were collected at one second intervals and these data were used to differentially correct the airborne GPS trajectory. Base station coordinates for each of the four sites are listed below:

Marmot Base monument processing summary coordinates:

A Leica SR530 dual frequency survey grade GPS receiver was set up over a survey monument at the Kananaskis Research Station. The coordinate for the monument was not known so a static base line was computed relative to the permanent CACS monitoring site in Calgary to facilitate accurate georegistration of the base station monument.

Master: KCRS Base
Antenna height: 1.564 m
Lat: 51.02854735
Long: -115.03238470
Elev: 1384.875 m (NAD83, Ellipsoidal hgt)

Wolf Creek primary base station coordinates:

Two Leica SR530 GPS base stations were set up to provide backup survey control; one by AGRG on the Alaska Highway and one by WLU IP3 researchers within Wolf Creek. However, the primary base station used for control of the airborne trajectory was the Whitehorse CACS, due it being the most accurate GPS base station data available locally and being available during the survey.

Master: WHITEHORSE_CACS
Antenna height: 0.000 m
Lat: 60.75051281
Long: -135.22211158
Elev: 1427.366 m (NAD83, Ellipsoidal hgt)

Scotty Creek base station coordinates:

Tow GPS base stations were used for airborne survey control over Scotty Creek. Both receivers were Leica SR530s; one operated by AGRG staff and located over the order one highway junction monument near the eastern edge of the survey area, and second operated by WLU research personnel located at the research camp within the watershed. Both GPS base stations were used for survey control. The research camp station was first differentially corrected to the highway monument to ensure both stations were accurately co-registered:

Master 1: HIGHWAY_JUNC
Antenna height: 0.000 m
Lat: 61.30822238

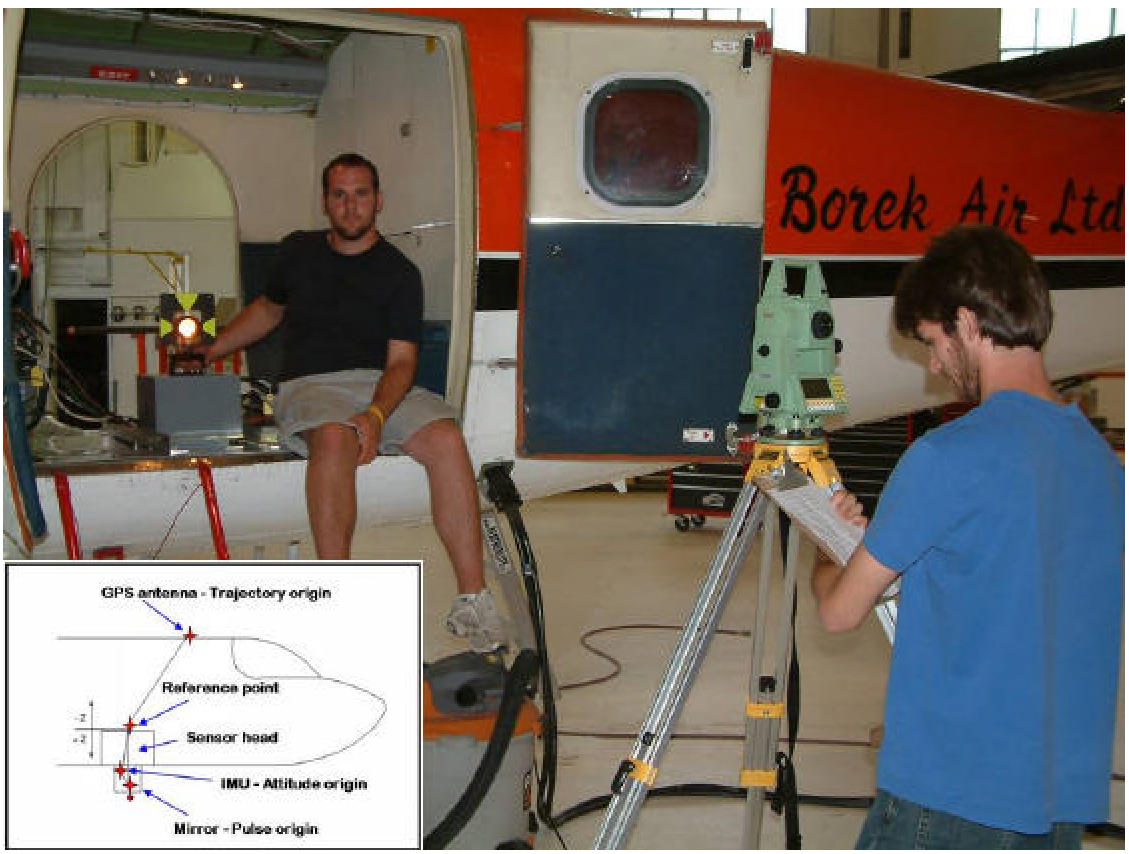
Long: -121.30610138
Elev: 272.284 m (NAD83, Ellipsoidal hgt)

Master 2: SCOTTY_BASE
Antenna height: 1.334 m
Lat: 61.44835813
Long: -121.23875363
Elev: 195.835 m (NAD83, Ellipsoidal hgt)

Baker Creek base station coordinates:

The Yellowknife CACS permanent GPS station was logging at one second intervals during the survey and so these data were used for airborne control.

Master: YELLOWKNIFE_CACS
Antenna height: 0.000 m
Lat: 62.48089541
Long: -114.48069801
Elev: 180.724 m (NAD83, Ellipsoidal hgt)



Installing the ALTM in the Twin Otter C-GKBG survey aircraft used for the missions (Kenn Borek Air – Calgary). AGRG Masters students (Pete Horne, SMU and Tristan Goulden, UNB) are surveying in the GPS eccentricity offsets to register the ALTM, GPS antenna and flight axis.

Laser point position computation:

Preliminary coverage processing was carried out while in the field but all final data integrations and outputs were performed at the AGRG lab in Nova Scotia. The steps are outlined below.

Step 1: Download and archive the ground base station GPS, airborne GPS, Inertial Measurement Unit (IMU) data, laser range and scanner data files.

Step 2: Differentially correct all GPS base station data files to same network reference frame. Software used = POSGPS (Applanix Corp., Ontario).

Step 3: Integrate multiple ground GPS base station files with airborne GPS file to differentially correct the airborne trajectory. Software used = POSGPS (Applanix Corp, Ontario).

Step 4: Integrate differentially corrected airborne GPS trajectory with IMU platform orientation data and introduce internal system component offsets between GPS antenna, IMU origin and scanner mirror origin (eccentricities) to generate the “smoothed best estimated trajectory” (SBET) containing both position and orientation data of the platform at the point of laser pulse emission. Software used = POSPROC (Applanix Corp, Ontario).

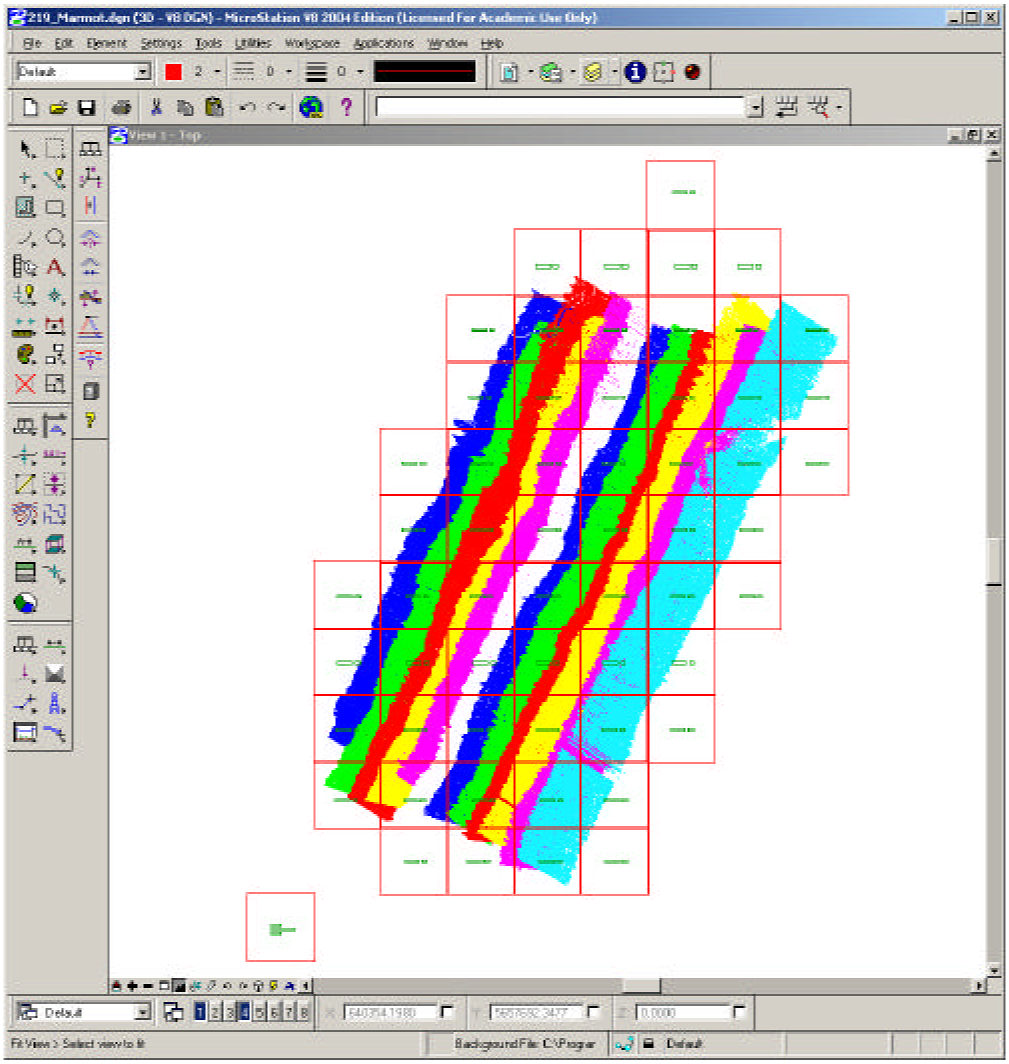
Step 5: Integrate SBET with laser range, scanner mirror position measurements and system calibration files. Software used = Dashmap (Optech Inc., Ontario).

Step 6 - Calibration: This is an iterative procedure; i.e. *data integration – calibration – data integration – refine calibration* ……… Ensure ALTM system components are aligned/calibrated using survey data over known targets (basic processing steps outlined above and below but specific calibration processing steps not discussed).

Step 7: Once alignment calibration is complete, laser point positions can be computed and outputted.

Laser data output:

The output from Dashmap is in LAS binary format and files are divided by survey flight line strip; i.e. one binary file per pass.



Flight line strips (Marmot Creek) loaded within the Terrascan software package

Reference System:

Units: Meters

Projection: Universal Transverse Mercator (UTM), Zones 8 - 11

Horizontal Datum: NAD83 CSRS

Elevation: Height above ellipsoid (GRS80)

For each emitted laser pulse, there was the possibility of up to four measured returns (first, intermediate, last and single returns). All measured return positions have been outputted.

Data post processing:

To convert the lidar data into a more useable format for IP3 personnel, we have performed several post processing procedures using the TerraScan and TerraMatch (Terrasolid, Finland) software packages. The general procedure applied to all five data sets is outline here. Any changes for specific data sets will follow.

1) **Tiling:** The geographic extents of the flight strips are large and individual files can easily exceed 1GB in size. For this reason, 1 km tiles (with a 20m buffer) were generated that completely surrounded each of the survey polygons defined by IP3 partners. Data for each tile were extracted and the procedures outlined below (steps 2 to 4) performed on each. The 20m buffer was included so that the tiles could be seamlessly mosaiced following raster DEM interpolation (provided the interpolation search radius is below the 20m buffer). An example of tile layout and numbering is shown below. Tile index images for all five data sets are included in Appendix A.

Example of tile numbering scheme for Sibblad Creek.

2) **Alignment:** Data was examined for mismatches between flight lines, using the TerraMatch design application. This is an iterative and manually intensive stage of processing. A ground classification procedure was first run on the data, processed by individual flightlines; the parameters for this classification are listed in Table 2.

Pre TerraMatch Ground Classification Macro : TerraGround2.mac

Step	Macro Code	From Class	To Class	Description
Step 1	(999,1,0)	Any	1	Moves all points to Class 1 (Default)
Step 2	("1",5,1,9.00,0)	1	5	Finds any isolated points within 9.0m of any other point and moves them to Class 5 (isolated points)
Step 3	(1,6,1,3.00,6.00,0)	1	6	Finds single low points more than 3.0m lower than others within 6.0m and moves them to Class 6 (single low points)
Step 4	(1,7,2,3.00,6.00,0)	1	7	Finds groups of max 2 low points, more than 3.0m lower than others within 6.0m and moves them to Class 7 (group low points)
Step 5	(1,2,1,20.0,88.00,7.00, 1.40,-1,3.0,0,2.0,0)	1	2	Classifies ground points from Class 1 to Class 2 (ground). Requires at least one ground point in a 20x20 metre area. A point is considered ground if its terrain angle is less than 88º, its iteration angle is less than 7º to the plane, and if its iteration distance is less than 1.4m to the plane.
Step 6	(2,100.0,999,8,50.00, 4000.00,0)	Any	8	Classify by height from ground; Max triangle 100.0m, Min height is 50m, Max height is 4000m.

Table 2. Macro routine used to classify data for TerraMatch processing. (Class numbers are arbitrary, making use of available structure within TerraScan.)

The data was then examined for misalignment in roll, pitch, heading, mirror scale and elevation shifts between each flight line. Two passes of the algorithm were made for each data set; the first to obtain roll, pitch, heading and scale correction values, the second for elevation shift values. These values were applied to the entire data set.

The Measure Match tool in TerraMatch allows the calculation of the difference in magnitude between individual flight lines in a data set. For each data set, the initial average magnitude and the final average magnitude value indicate a measure of the improved match of flight lines through the TerraMatch process. These values are listed in the Study Area Specifics following.
All data sets required alignment at this stage, with the exception of Scotty Creek and Baker Creek, where it was determined that no further improvement to the data would be obtained by the TerraMatch routines.

3) **Data cleaning:** This involved isolating high and low laser pulse returns that either floated well above the canopy surface or penetrated well below the true ground surface. Such data errors occur due to bird strike,

atmospheric vapour/clouds/aerosols, and or multi-path of the laser pulse. This is a semi manual procedure that requires visual inspection of cross sections through the point cloud and deletion of points that occur outside the bounds of the ground to canopy surface envelope. This procedure can be automated but best results are obtained if it is done manually.

4) **Ground classification:** Ground returns were classified from the point cloud using a proprietary algorithm within Terrascan that interrogates the morphological properties of the point cloud. There are several user configurable parameters; the following settings were used:

   At least one ground point is required in a 20x20 metre area. (Footprint = 20m). A point is considered ground if its terrain angle is less than 88º, its iteration angle is less than 6º to the plane, and if its iteration distance is less than 1.4m to the plane. Any deviation from this is listed in the Study Area Specifics following.

   This processing allows the output of ACSII format ground files.

5) **Geoid Adjustment:** The data sets were adjusted to account for local geoidal undulation. Orthometric heights and geoid separation were determined using the HTv2.0 model (CGG2000 Scientific model + HRG01 Corrector Surface, allowing the direct transformation of NAD83 or ITRF ellipsoidal heights to CGVD28 orthometric heights).

6) **Raster Processing:** The ground only XYZI (Easting, Northing, Elevation and Intensity) files were further processed through the Surfer (Golden Software, Inc) grid format to produce ArcGIS ASCII raster files. All files were gridded with 1m node spacing, using a 2nd power Inverse Distance to Power function, with a 15m search radius, and the 20m buffer was removed from each tile.

7) **Return or 'echo' classification:** All returns within the point cloud were separated into classes of either first, intermediate, last or single return types and place into separate point classes. This enables further refinement or information extraction routines to be generated that require the return class information.

Study Area Specifics

Sibbald Creek

Total Points Observed:	72,030,710
Minimum Z:	-1525.17 m
Maximum Z:	+2259.25 m
Initial average magnitude:	0.17550 m
Final average magnitude:	0.09921 m

An iteration angle of 7º was used in the final ground classification routine.
…………………

Marmot Creek

Total Points Observed:	98,535,848
Minimum Z:	-742.18 m
Maximum Z:	+3808.13 m

Initial average magnitude:	0.45617 m
Final average magnitude:	0.28487 m

…………………

Wolf Creek

Total Points Observed:	222,254,965
Minimum Z:	-1669.22 m
Maximum Z:	+2752.54 m

Initial average magnitude:	0.50165 m
Final average magnitude:	0.19762 m

An iteration angle of 7º was used in the final ground classification routine.
…………………

Scotty Creek

Total Points Observed:	224,671,654
Minimum Z:	-4388.63 m
Maximum Z:	+826.54 m

No TerraMatch processing performed.

An iteration angle of 8º, and a 1.5m distance to plane was used in the final ground classification routine.
…………………

Baker Creek

Total Points Observed:	365,448,440
Minimum Z:	-1935.21 m
Maximum Z:	+1273.62 m

No TerraMatch processing performed.
………………

Data delivery formats:

The data is separated by study area, denoted by the folder named by the year_julianday_area designation. Data for each area are delivered in five separate directories as illustrated below for the Sibbald Creek study area.

The data classified into ground/non-ground are provided in LAS binary format in the "LAS_All_Pts" folders. Each file is named area_0#_All_Pts.las (area = study area, 0# = tile number).These files cover a greater geographic coverage than the specified survey area polygons.

No individual LAS file exceeds 1 GB. Table 3 illustrates final file sizes. See: http://www.asprs.org/society/committees/lidar/lidar_format.html
…………………

The ground classified tiles are placed in the "XYZI_Ground_ONLY" folders. Table 3 illustrates final file sizes, with file sizes ranging from ~ 10MB to 100MB. Each file is named area_**_G.xyz (** = tile number). In each of these files, all are point data in space delimited ASCII format with no header:

[Easting] [Northing] [Elevation] [Intensity]

e.g.:

622516.02 4781480.08 61.47 11.4
622517.47 4781480.34 61.37 9.8
622517.89 4781481.47 61.34 8.4
622513.88 4781480.79 61.36 11.7
622512.37 4781480.53 61.34 12.5
622511.87 4781480.44 61.34 7.8
…………………………

The tiles of data that are classified by return (first, intermediate, last, single) are placed within the "CXYZI_All_Pts" folders. Table 3 illustrates final file sizes, with file sizes ranging from ~ 100MB to 1GB. Each file is named area_**_ALL_Echo.xyz (** = tile number). In each of these files, are all point data in space delimited ASCII format with no header:

[Class] [Easting] [Northing] [Elevation]

Class 1 = first
Class 2 = intermediate
Class 3 = last
Class 4 = single

e.g.:

3 430198.79 5042297.72 228.24
3 430197.90 5042299.94 221.48
3 430195.06 5042305.88 220.86
1 430198.21 5042307.54 232.15
2 430196.93 5042306.84 228.12
3 430194.98 5042305.78 222.00
4 430194.34 5042305.38 221.42
4 430194.47 5042305.55 221.53
1 430198.29 5042307.68 232.13
2 430196.99 5042306.97 228.04
3 430195.18 5042305.99 222.38
1 430198.65 5042307.93 231.94
2 430197.42 5042307.26 228.06
3 430195.14 5042306.02 220.90
3 430195.50 5042306.27 220.71
4 430198.55 5042310.43 231.83
…………………

The ground classified tiles were processed to obtain ArcGIS ASC raster files, ready to be imported into ArcGIS using the ASCII to Raster conversion tool. These files are placed in the "ArcGIS_ASCII" folder and Table 3 illustrates final file sizes, with file sizes ranging from ~ 2MB to 25MB. Each file is named area_**_G_####_^^^^.ASC (** = tile number, #### = Easting, ^^^^ = Northing). In each of these files, all are raster data in space delimited ASCII format with the following header information:

ncols 717
nrows 1001
xllcorner 621783.5
yllcorner 4781499.5
cellsize 1
NODATA_value 1.70141e+038

53.318376563746 53.34369345139 53.379997975828 53.375321348723 53.394974975182 53.437640526276 53.467279689265 53.429342681319 53.543733893739 53.600643783567
…………………………

Finally, JPEG images of each tile are included in the “JPEG_Shaded_Relief” folder for each block. The image is a shaded relief representation of the tile, at 1m resolution, with the tile name superimposed. These files follow the naming convention for the ArcGIS ASC files, with “_SR” appended to each file.

	Sibbald	Marmot	Wolf	Scotty	Baker
ArcGIS	295 MB	2.35 GB	5.58 GB	5.73 GB	4.59 GB
CXYZI	2.26 GB	3.20 GB	7.34 GB	8.02 GB	11.1 GB
JPEG	3.44 MB	6.75 MB	17.6 MB	44.7 MB	27.7 MB
LAS_All_Pts	1.76 GB	2.49 GB	5.74 GB	6.41 GB	8.93 GB
XYZI_Ground	617 MB	1.42 GB	4.06 GB	1.27 GB	4.87 GB

Table 3. Final data folders and sizes

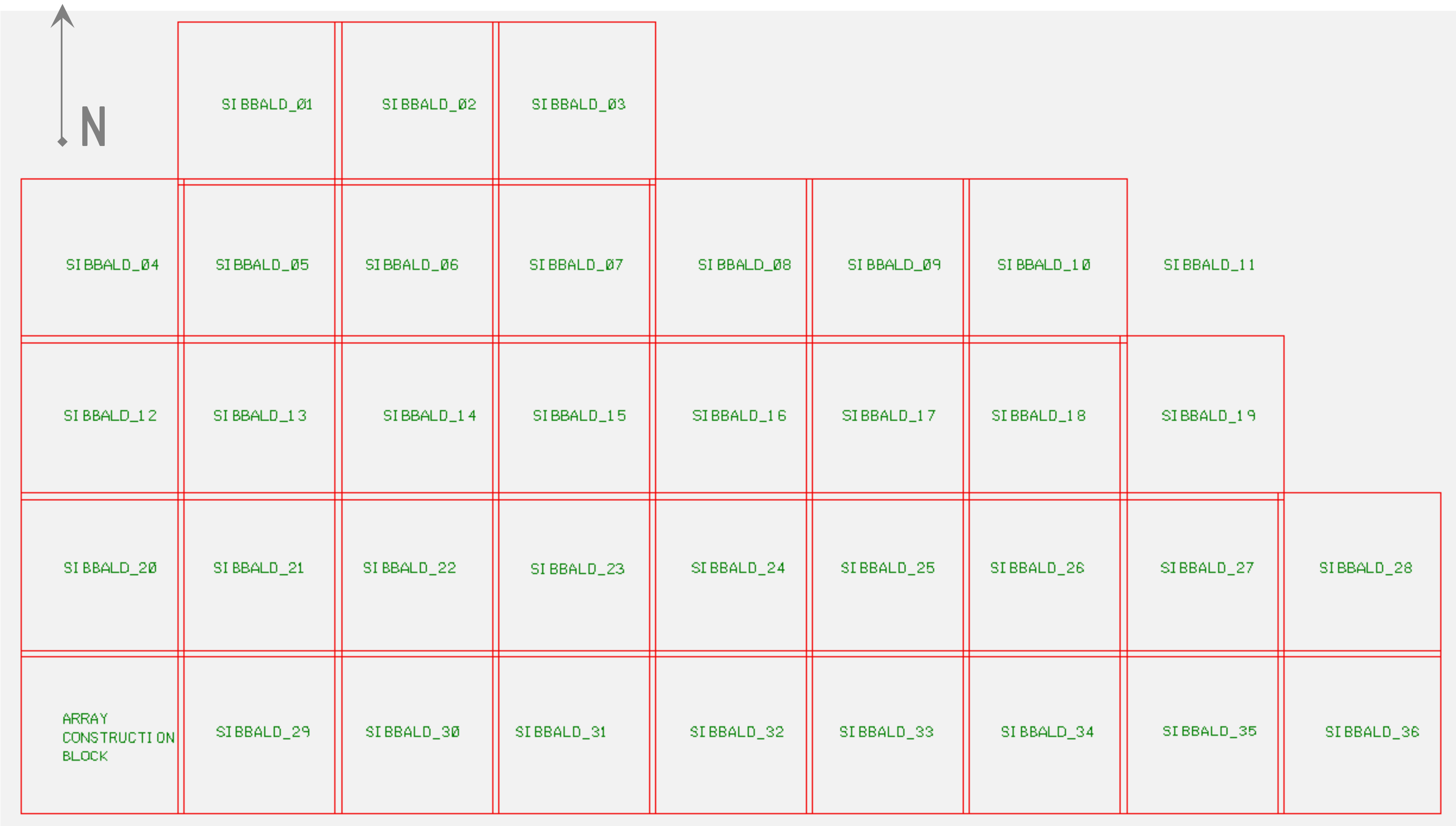
The *C-CLEAR* team hanging out in Yellowknife. From left to right:

Laura Chasmer, lidar operations (*Queen's* PhD student); Allyson Fox, lidar operations (*AGRG* research associate); Kevin Garroway, ground support (*Dalhousie U* MEng student); Dr John Barlow, ground support (*U Sask* faculty); Doug Stiff, ground support (*Acadia U* MSc student); Dr Chris Hopkinson, team leader (*AGRG* research scientist); Bob Heath, survey pilot (*Kenn Borek*).

Missing: Musa Gershuny, Optech lidar technician. *Kenn Borek Air* also rotated four flight engineers during the course of the campaign.

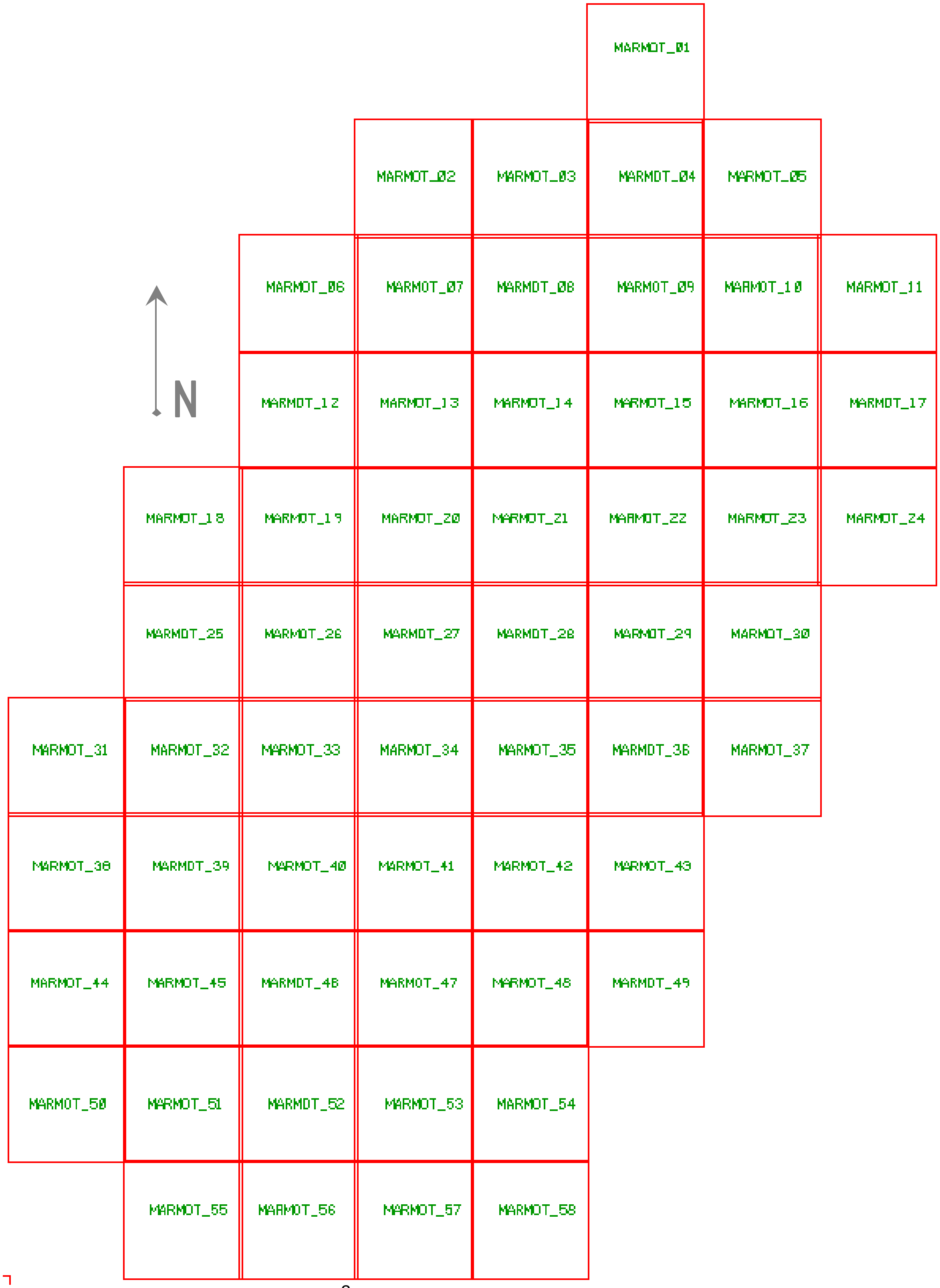
Appendix A – Tile Index Images

Sibbald Creek Index Map



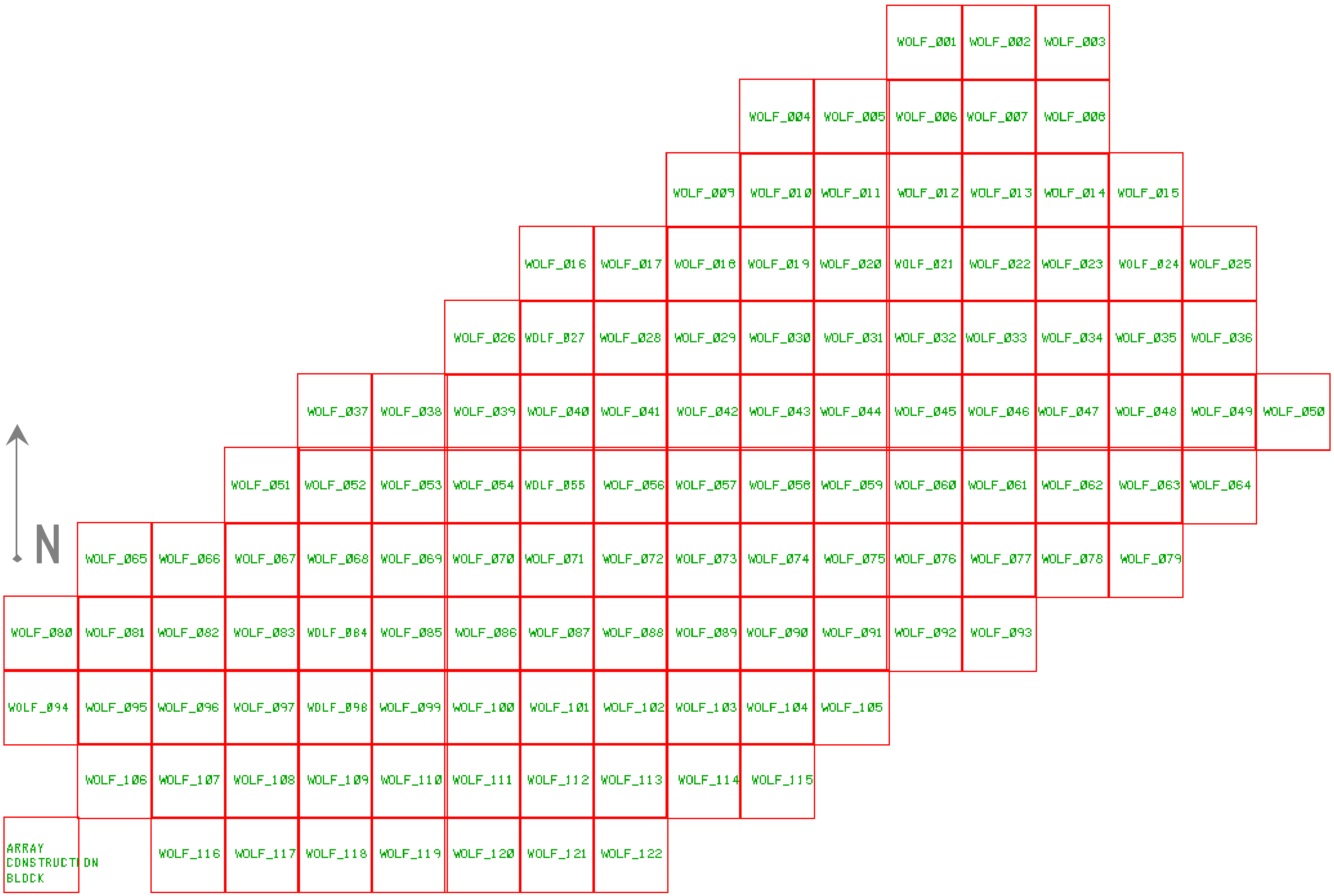
Each tile represents one 1 km^2 of data. Note that there is no file associated with block 11 (contained no data).

Marmot Creek Index Map



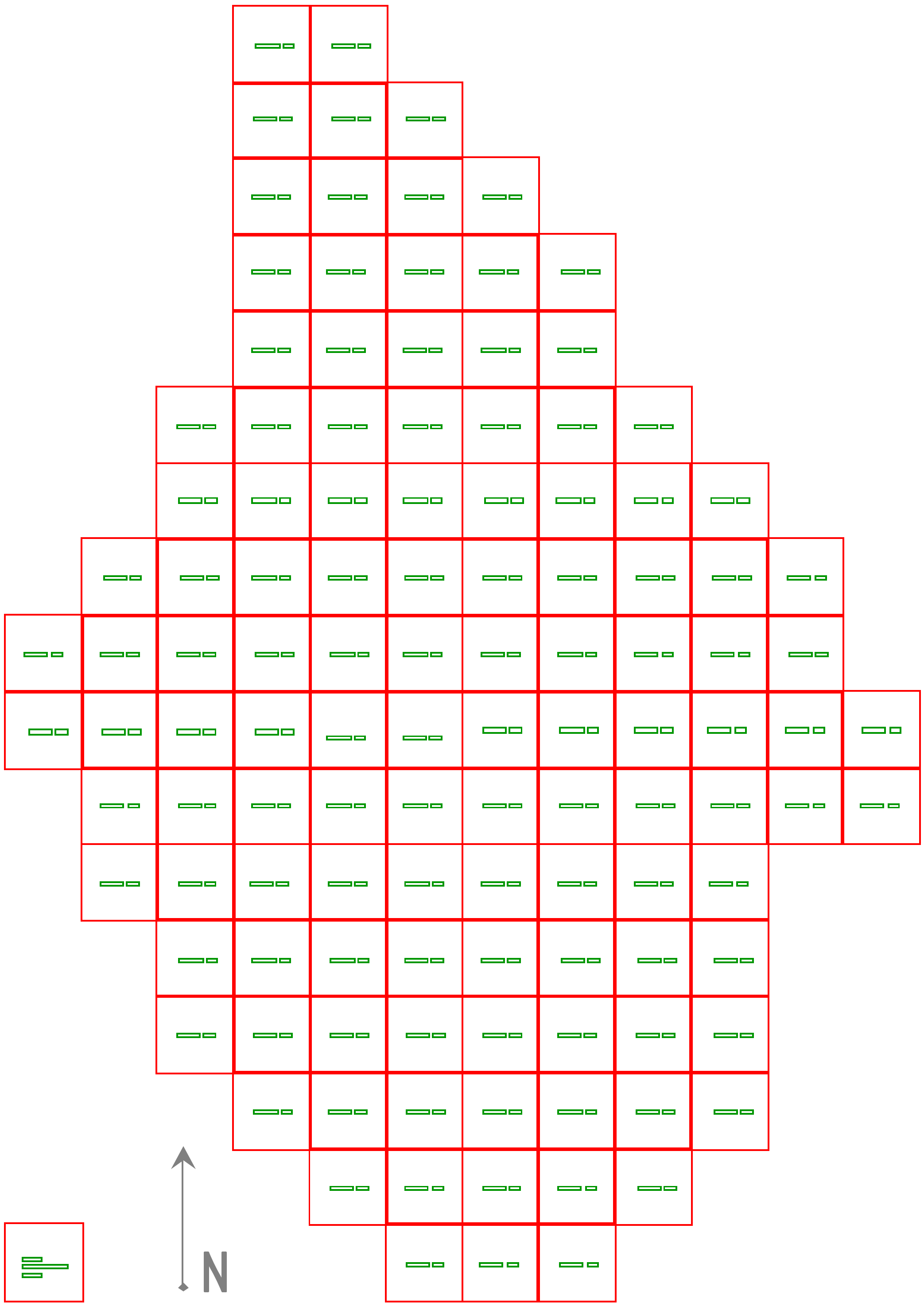
Each tile represents one 2 km^2 of data.

Wolf Creek Index Map

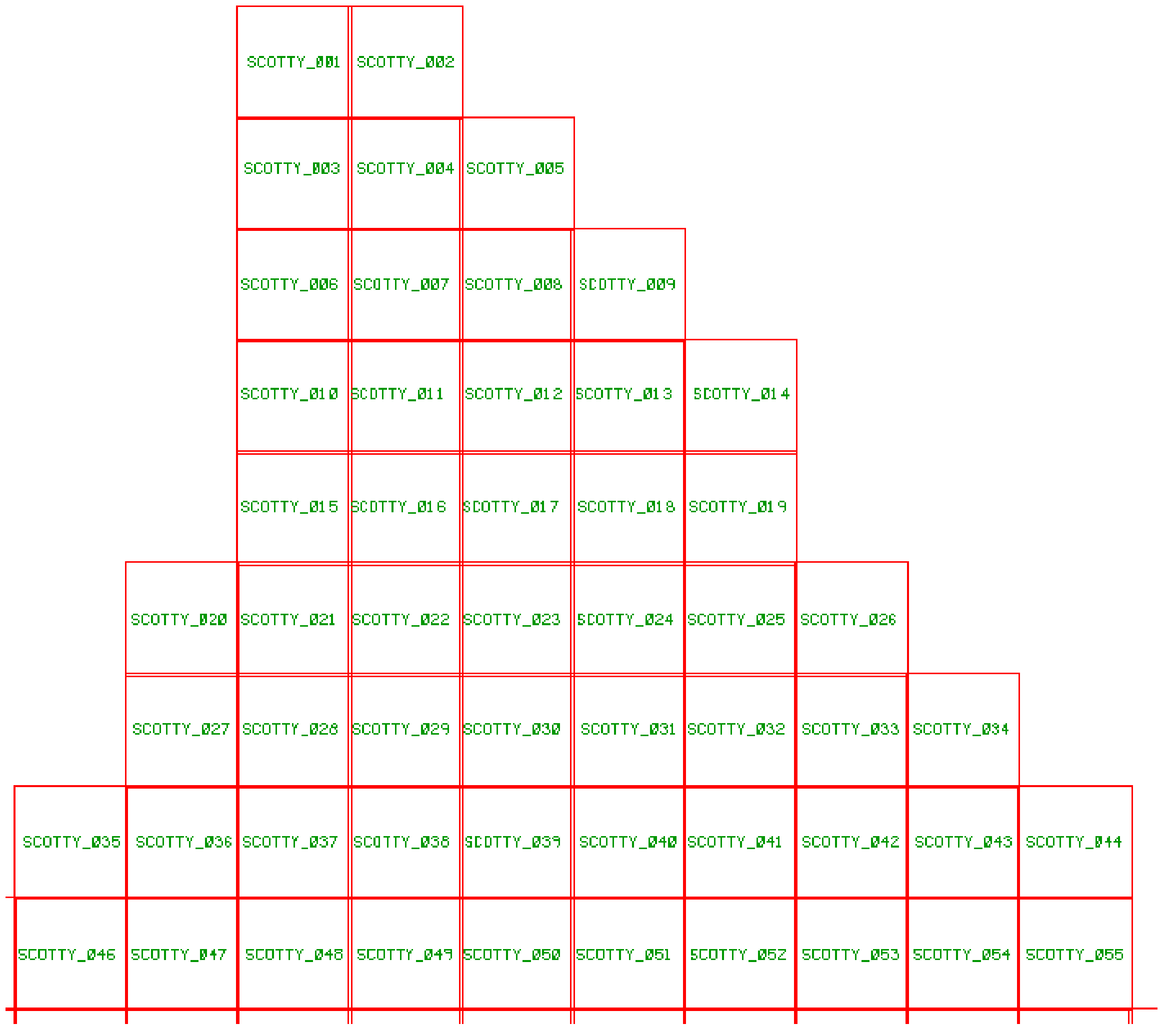


Each tile represents one 2 km^2 of data.

Scotty Creek Index Map



Each tile represents one 2 km2 of data. Zoomed in images following:


SCOTTY_001
SCOTTY_002
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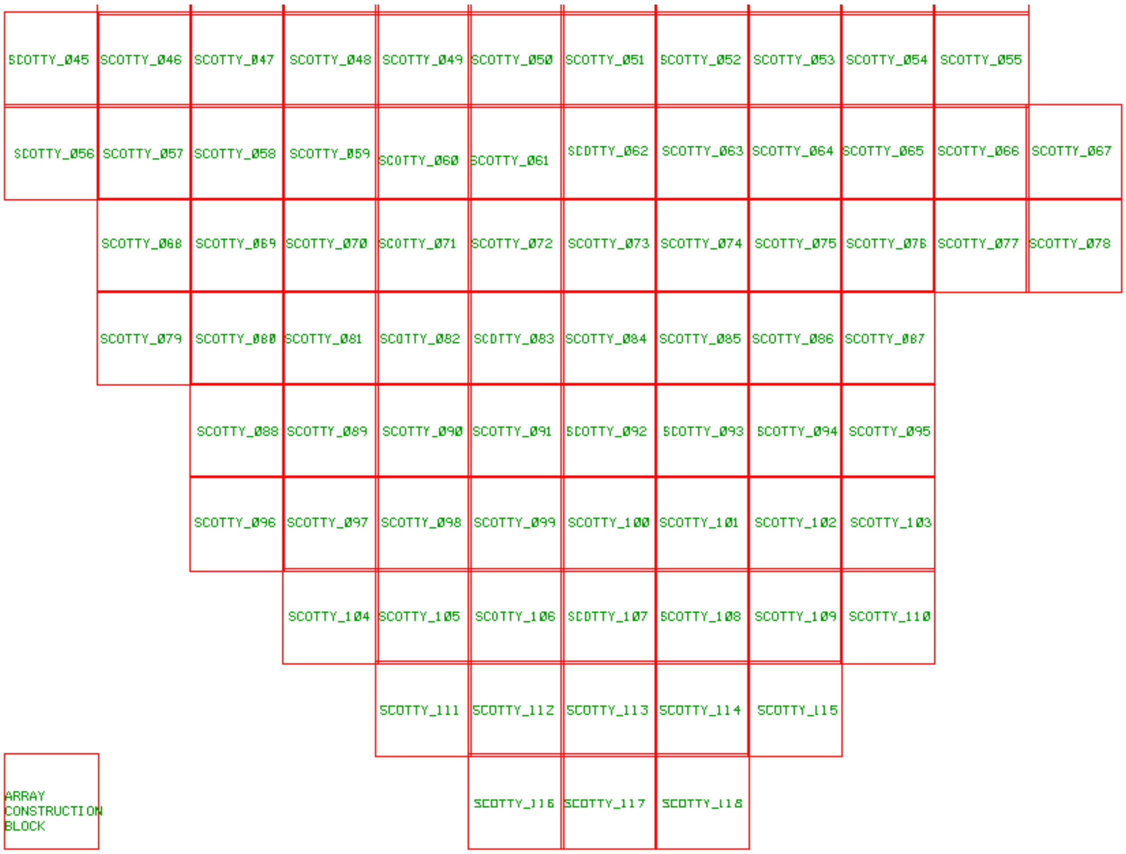
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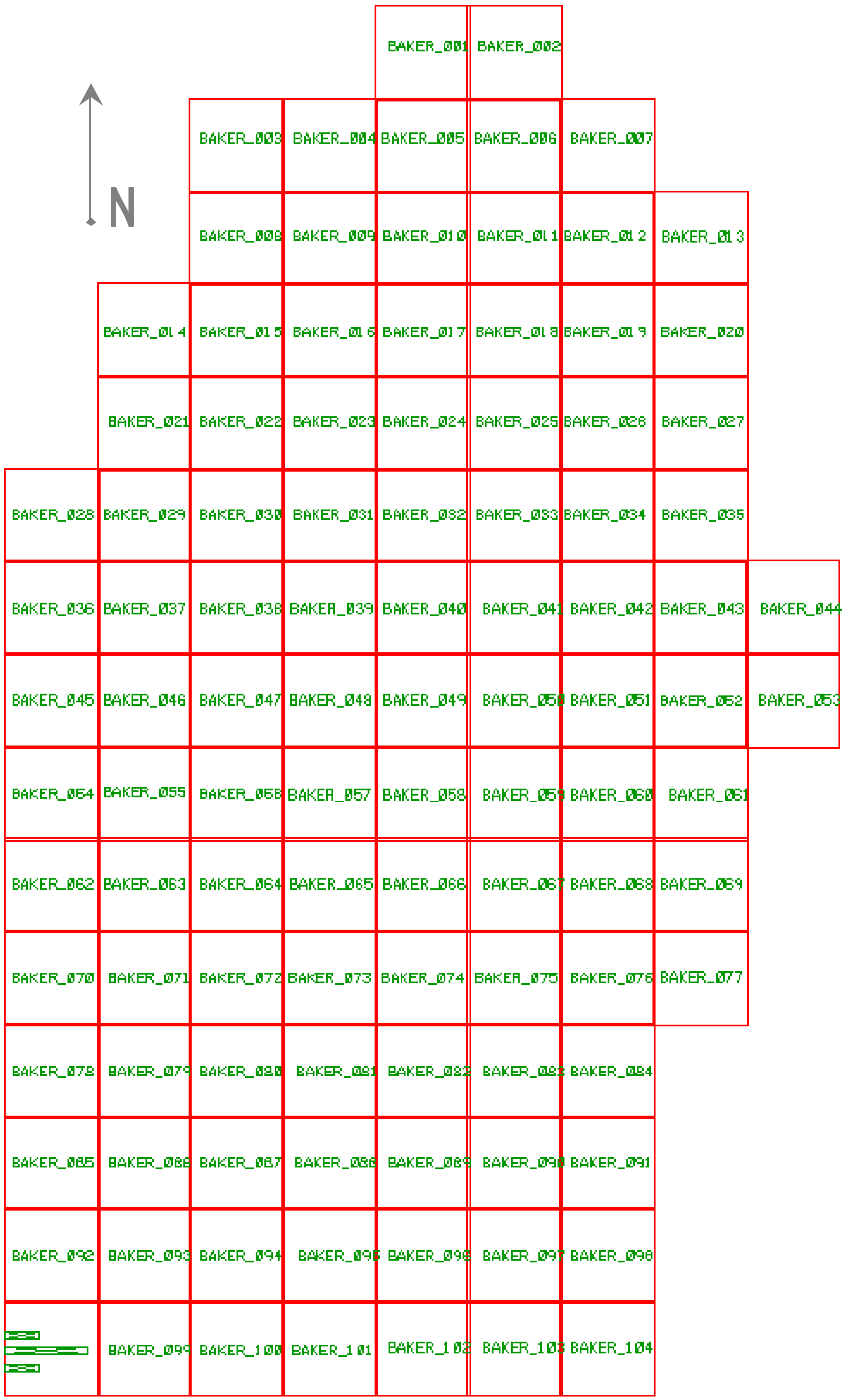
SCOTTY_117
SCOTTY_118
ARRAY
CONSTRUCTION
BLOCK

Baker Creek Index Map



Each tile represents one 2 km2 of data.