State of Oregon
Oregon Department of Geology and Mineral Industries
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ACQUISITION OF AIRBORNE THERMAL INFRARED (TIR) AND LIDAR IMAGERY IN CENTRAL AND EASTERN OREGON
TECHNICAL SPECIFICATIONS

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AIRBORNE THERMAL INFRARED TECHNICAL SPECIFICATIONS

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1.0 INTRODUCTION

The Oregon Department of Geology and Mineral Industries (DOGAMI), together with the states of Idaho, Utah, and Nevada formed the Great Basin Consortium, and as participants in the National Geothermal Data System (NGDS) project, this consortium received supplemental federal assistance funds (American Recovery and Reinvestment Act of 2009) from the US Energy Department's (USDoE) Geothermal Technologies Program through the Arizona Geological Survey for new geothermal data collection (expanding Task 2.4 of the project objectives). DOGAMI's portion of the federal assistance funds supported the following work:

- A pilot study employing airborne thermal infrared (TIR) and co-acquired Lidar (an acronym for light detection and ranging) directed at detecting potentially small-magnitude, geothermally-elevated ground temperatures.
- The drilling of three thermal gradient wells.

This report, *Acquisition of Airborne Thermal Infrared (TIR) and Lidar Imagery in Central and Eastern Oregon, Technical Specifications*, was prepared by the Oregon Department of Geology and Mineral Industries (DOGAMI) to satisfy Task 2 of the TIR pilot study's Scope of Work, and document the process that led to the acquisition of the TIR imagery and co-acquired lidar data. The aim of acquiring airborne TIR imagery was to explore the prospect—and challenges—of utilizing TIR mapping to discriminate potentially small-magnitude, geothermally-elevated ground temperatures, which may be associated with geothermal resources.

The initial plan was to acquire the TIR imagery early enough in the grant period (see Chapter 3, Acknowledgments) to be able to use the results to site thermal gradient holes within one or more geothermally-related, land-surface temperature anomalies. However, that proved impractical given the time constraints of permitting and bidding the drilling. In the end, the locations for drilling all three thermal gradient holes fall within the footprint of the imagery acquisitions at sites dictated largely by permitting expedience. The reader is referred Niewendorp (2013) for the report describing the drilling of the thermal gradient wells.

The TIR pilot study advanced through five (5) phases that included selection of the TIR flight areas, development of the initial proposal, State and federal permitting, bidding, and the collection of the TIR imagery. That process resulted in the collection of a data set, covering five flight areas shown in Figure 1.1. A companion report, "*Using Airborne Thermal Infrared and lidar imagery to search for geothermal anomalies in Oregon*", is an analysis of the TIR imagery for the Summer Lake flight area (Block 1) (Madin and others, 2013).

For the convenience of the reader, this report is divided into four chapters as follows:

- Chapter 1 is this current chapter and describes the project participants, TIR flight area characteristics, agency required permits and clearance, and contracting.
- Chapter 2 describes specifications and deliverables.
- Chapter 3 is project acknowledgments followed by Chapter 4 with references.

1.1 PROJECT PARTICIPANTS

Work described in this report was conducted by the following participants:

- DOGAMI handled the management of the project.
- Bidding, procurement, and contacting were carried out by the Oregon Department of Administrative Service, Enterprise Goods and Services/Procurement Services.

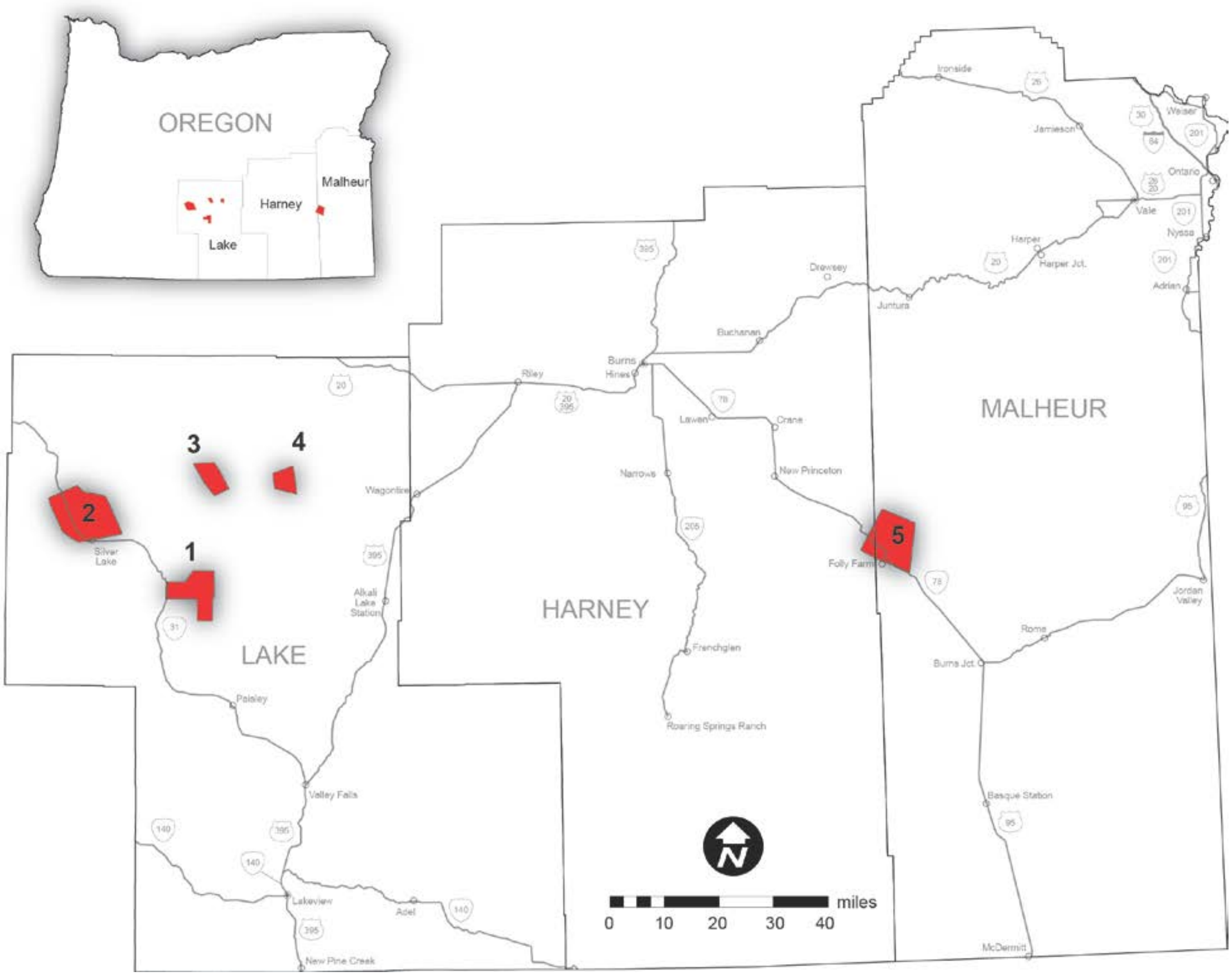

Figure 1.1: Location map of the five TIR flight areas (red) in parts of Lake, Harney, and Malheur counties. Numbers are keyed to blocks in Table 1.1. Combined the five flight areas represented 257 square miles. Land cover in each flight area is typical of high desert, e.g. sage brush, junipers, etc. and the topography ranged from flat lying to mountainous. TIR imagery and co-acquired lidar cost $582/sq mi

- Watershed Sciences, Corvallis, Oregon (The “Vendor”) was retained to obtain the TIR imagery and the co-acquired lidar data.

1.2 TIR FLIGHT AREA CHARACTERISTICS

The TIR flights for this study covered areas of public lands either lacking geothermal information or those with an indication of geothermal potential that are near or reasonably close to transmission power lines. Equally as important in the selection of flight areas was the criteria used to exclude certain locales, such as:

- Locales of active and inactive geothermal leases,
- Presence of past geothermally-related exploration drilling (Niewendorp and others, 2012),
- And, environmental restrictions, such as Sage Grouse habitat and Wilderness Study areas.

Summarized below in Table 1.1 are geographic details of the selected TIR flight areas as well as acquisition dates.

Table 1.1: TIR flight area details

Flight areas	Location	County	Acres	Square miles	Images and data Acquired
Block 1	Summer Lake	Lake	30,916	46	3/4/2012
Block 2	Paulina Marsh	Lake	56,405	88	3/8/2012 3/9/2012
Block 3	Christmas Valley	Lake	13,057	20	3/3/2012
Block 4	Oregon Military Department	Lake	9,708	15	3/5/2012
Block 5	Baker Pass	Harney/ Malheur	44,846	70	4/6/2012 4/7/2012 4/8/2012

1.3 AGENCY REQUIRED PERMITS AND CLEARANCE

National Environmental Policy Act (NEPA) scrutiny and clearance through U.S. Department of Energy was necessary to proceed with the acquisition of TIR imagery and lidar data. The reader can follow a hyperlink in Appendix A to download a copy of the NEPA permit.

1.4 CONTRACTING

As mentioned earlier, the Oregon Department of Revenue, Enterprise Goods and Services/Procurement Services provided “Client Services” on the solicitation of Request for Proposals (RFP), called “Georeferenced Airborne Thermal Infrared Imaging.” This RFP was published on ORPIN (Oregon Procurement Information Network), which is administered by the State Procurement Office. Timeline of this process is listed in Table 1.2. The reader can follow a hyperlink in Appendix A to download a copy of the contract between DOGAMI and the Vendor.

Table 1.2: Contracting timeline

Date	Description
7/5/2011	Development of TIR scope of work begins
10/6/2011	RFP sent to DAS Client Service for processing
12/19/12	RFP post on ORPIN; Solicitation for RFP 107-2888-11, Georeferenced Airborne Thermal Infrared Imaging
1/9/2012	Solicitation closed
2/9/2012	Executed Contract for Personal/Professional Services; Kick-off meeting
7/25/2012	Project completion notice

2.0 SPECIFICATIONS AND DELIVERABLES

2.1 TIR IMAGERY

Of particular importance was to collect TIR images when both air and surface temperatures were at their lowest level. Having this objective in mind acquisition of the TIR measurements occurred during the winter and early spring months of January through April at times coincident with early morning hours (12:00 a.m. to 6:00 a.m.). This also meant that flight planning had to be responsiveness with respect to weather conditions, which were unpredictable. Table 2.1 lists flight parameters along with equipment and TIR imagery specifications, followed by Table 2.2 of TIR deliverables that DOGAMI received from the Vendor:

Table 2.1: TIR imagery specifications

Equipment/Acquisition Requirements	Description
FLIR Systems SC6000 (LWIR) sensor	The TIR sensor views long wave infrared in the 8-9 µm range and 14-bit digital frames are directly sent from the sensor to an on-board computer. The equipment is capable of a thermal resolution of ±0.1°C.
Airborne GPS	(1) The TIR sensor was coupled with an airborne GPS and navigation system designed to provide high-accuracy exterior orientation for each thermal image. (2) The system provides x, y, z coordinates and roll, pitch and yaw orientation information.
Flight Planning	(1) Vendor deployed a stable "fixed wing" airborne platform grid survey for each flight area. (2) Thermal images were collected at the appropriate 3,000 of altitude to achieve an optimal native spatial resolution, ± 0.5-meter. (3) Each flight line overlapped, a minimum of 30% side-lap between lines and 30% vertical-lap between images.
Conditions during the Data Acquisition	(1) The flight(s) were conducted during the early morning hours between 2:00 a.m. and 6:00 a.m. and took place in the months of January through April. (2) Snow cover on the ground was negligible. By "negligible" we mean that the proportion of snow cover can range from a trace up to 0.5 inches. (3) Wind speeds were less than 15 knots (17.3 mph). (4) No fog, smoke, or other variables were present that would otherwise degrade data collection and image quality.
Thermal Accuracy	Verification of Radiant Accuracy between on-ground data (kinetic temperatures) collected during the time frame of each TIR survey and radiant temperatures derived from the TIR images was <0.5°C over the course of each flight.
GIS-ready polygon and point files	Point shapefile showing the centroid location and acquisition time of the thermal image frames within each flight area.
	Location (coordinates) and serial number of "on-ground" data logger(s) used to calibrate the TIR measurements for each flight area.
	Polygon shapefile delineating thermal features.
Mosaic	Thermal infrared image mosaic in standard GIS compatible GeoTiff format. Cell values reported as radiant temperature.
Rectified Images	The TIR imagery sets are fully orthorectified and tiled in a standard GIS compatible format. Cell values reported as radiant temperature.
Raw Thermal Image Frames	Raw thermal infrared images in units of radiance, e.g.. Watt per square meter per steradian ($W/m^2/sr$).

Note: Projection of data is UTM Zone 10N: NAD 83 or UTM Zone 11N: NAD 83 depending on the UTM Zone where the flight area(s) are located.

Table 2.2: TIR deliverables

Product	Format	Resolution	Deliverable Description
Thermal Image Centroid	shapefile	double	Geometry files depicting the geospatial area and locations associated with deliverables.
Ground Sensor Locations	shapefile	double	Geometry files depicting the geospatial area and locations associated with deliverables.
Project and Data Index	shapefile	double	Geometry files depicting the geospatial area and locations associated with deliverables.
TIR Mosaics	GeoTiff	0.5 meters	Mosaiced thermal infrared imagery created from rectified TIR frames.
TIR Native Images	GeoTiff	0.5 meters	Raw unrectified thermal infrared images output directly from the sensor.
TIR Rectified Images	Imagine Images	0.5 meters	Ortho rectified thermal infrared images. Ortho rectification was achieved using proprietary photogrammetric software utilizing GPS and IMU data acquiring during data collection. Lidar bare earth was used as topography for ortho correction.
Comprehensive Report	pdf	n/a	Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

n/a = not applicable

2.2 LIDAR DATA

Lidar was co-acquired with TIR so coverage is identical. As described in Part 2, "Preliminary Analysis of Airborne Thermal Infrared and lidar imagery to search for geothermal anomalies in Oregon", the lidar data was collected in order to help accurately georeference the TIR imagery and to provide a detailed and accurate paired basemap for analysis of the thermal imagery (Madin and others, 2013). The lidar data collected for the TIR Pilot Study had high accuracy and resolution, corresponding to USGS Quality Level 1 (Heidemann, 2012), although they do not meet the resolution specifications of the vast majority of Oregon lidar collected by the Oregon Lidar Consortium. Table 2.3 summarizes the lidar technical characteristics, followed by Table 2.4 of lidar deliverables that DOGAMI received from the Vendor.

The primary lidar products used for this project were the bare earth and highest hit Digital Elevation Models (DEM) illustrated in Figure 2.1. These DEMs have a native resolution of 1 m and were used to orthorectify the TIR imagery. As a result the correspondence between topographic features in the lidar and their thermal signatures is excellent (Figure 2.2). For analytical purposes, Madin and others (2013) created new DEMs from the lidar point data with a resolution of 0.5 m. These grids are detailed enough to resolve fine features of vegetation such as grasses and sagebrush.

Table 2.3: Lidar specifications

Specification or Deliverable	Description
Lidar Specifications	Multi-swath pulse density = ≥4 pulses/m^2 Field-of-View = ≤28 deg FOV (±14 deg nadir) Side-lap = 50% (100% overlap) Returns per pulse: Up to four Maximum GPS Baseline: 13nmi GPS PDOP: ≤3.0 GPS Satellite Constellation: ≥6.0 Vertical RMSE (slope <20^o): ≤ 15.0 cm (2.3 cm RMSE achieved)
Aircraft Trajectories (SBET files)	Aircraft position (easting, northing, elevation), altitude (heading, pitch, roll), velocity, and GPS time recorded at regular intervals of 1 second or less. May include additional attributes. *ASCII text or ESRI Shapefile format*
All Return Point Cloud	All Point files will include the following fields: X,Y,Z (to nearest 0.001 meter), Return Intensity, Return Number, Point Classification (for classified point cloud), Scan Angle, GPS time (Adjusted, time reported to nearest microsecond or better).
	Point families were maintained: LAS V 1.2 format
	Point classifications: 1) processed, unclassified; 2) bare earth
Bare Earth Surface Model	Raster of ground surface, interpolated via triangulated irregular network from identified ground points. 1 -meter resolution (achieved), ESRI floating point GRID.
Report of Survey	Digital text report that describes survey methods, results, accuracy assessments, including internal reproducibility, and absolute accuracy, file formats, naming conventions, tiling schemes.
Formal Metadata	GIS-compatible data and files will be explained with XML format metadata that follows the Federal Geographic Data Committees (FGDC) Content Standard for GeoSpatial Data.

Note: Lidar data co-acquired with the TIR imagery. Vender performed Lidar processing and related analysis for each flight area. Projection of data is UTM Zone 10N: NAD 83 or UTM Zone 11N: NAD 83 depending on the UTM Zone where the flight areas are located.

Table 2.4: Lidar deliverables

Product	Format	Resolution	Deliverable Description
Aircraft Trajectories	shapefile	1 second	File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting (meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees). Measurements are collected at one second intervals.
All Return Point Cloud	LAS	5.4 pulses/m^2	Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
Bare Earth DEM	grid (ArcInfo)	1 meter	Tin interpolated grids created from lidar ground returns.
Report of Survey	pdf	n/a	
Formal Metadata	xml		FGDC

n/a = not applicable

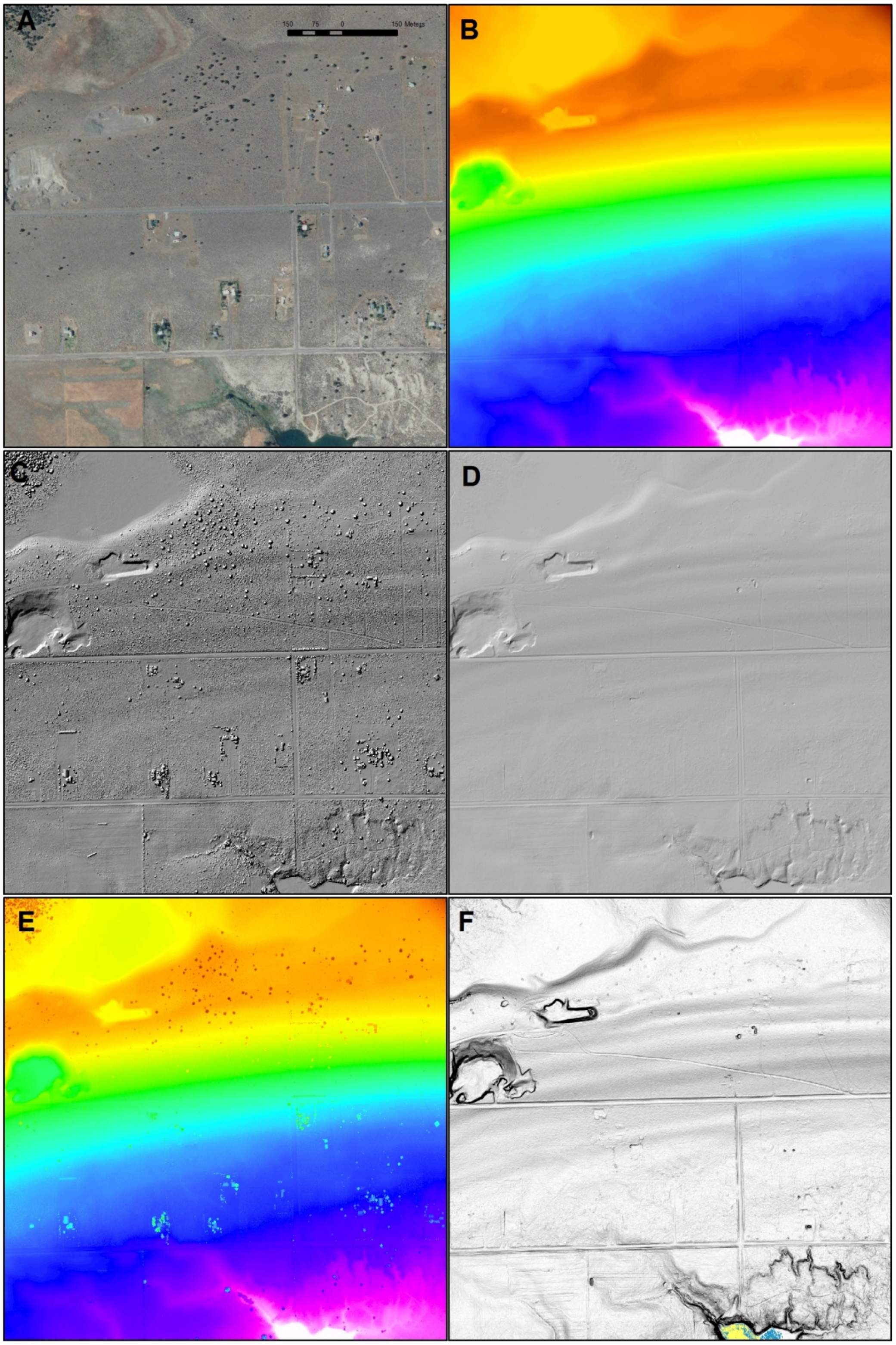

Figure 2.1: Example of lidar imagery (Bare Earth Grids: Tin interpolated grids created from lidar ground returns; Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 1 meter neighborhood.). A. orthophotography; B. lidar bare earth elevation; C. lidar highest hit hillshade; D. lidar bare earth hillshade; E. lidar highest hit elevation; F. lidar bare earth slopeshde (from Madin and others, 2013)

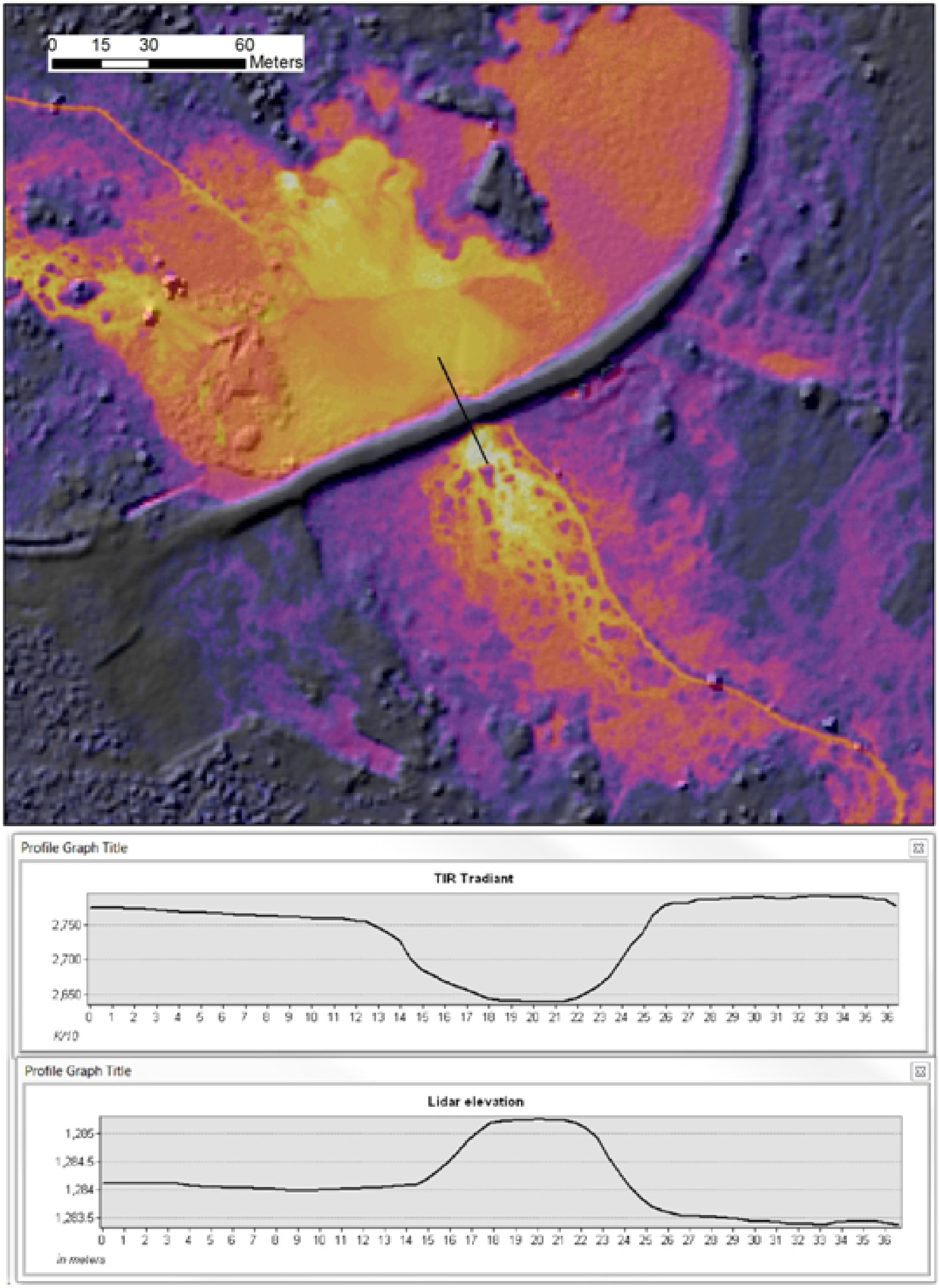

Figure 2.2: Illustration of the spatial registration of TIR and lidar imagery. Top image shows TIR imagery draped on lidar slopeshade, black line is location of profile crossing dike separating two relatively warm water bodies. Profiles across dike show close registration of image sets (from Madin and others, 2013)

2.3 DELIVERABLES

Listed below in Table 2.5 are final deliverables furnished by the Vendor as documentation that all data met project specific standards.

Table 2.5: Vendor deliverable documentation

Date	Source	Report
7/12/2012	Vendor	Airborne Remote Sensing Thermal Infrared & Lidar: Summer Lake, Oregon; Delivery 1 v.2
7/13/2012	Vendor	Airborne Remote Sensing Thermal Infrared & Lidar: Christmas Valley, Oregon Military, Paulina Marsh, & Baker Pass, Oregon; Delivery 2 v.2

2.3.1 quality control

The Vendor agreed to certain conditions of data quality and standards as stated in Part II of Exhibit A, Statement of Work for Personal/Professional Services Contract #107-2888-11. DOGAMI staff reviewed the data deliverables for completeness and data were checked for quality, which included examining TIR imagery and lidar data for errors (Table 2.6).

Table 2.6: TIR and lidar quality check

Product	Data Check	Description
TIR	Horizontal Accuracy	File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting (meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees). Measurements are collected at one second intervals.
TIR	Thermal Consistency and Accuracy	TIR mosaics were visually examined in ArcGIS using multiple raster stretches to detect patterning consistent with temperature offsets between image frames.
TIR	Data Anomalies and Data Description	Tin interpolated grids created from lidar ground returns.
Lidar	Consistency Analysis	DOGAMI has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between flight lines. DOGAMI measures consistency offsets throughout delivered datasets to ensure that project specifications are met.
Lidar	Visual Analysis	Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns.
Lidar	Absolute Accuracy Analysis	Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground control points (GCP) obtained throughout the lidar sampling area. Vertical accuracy analysis consisted of differencing Vendor provided control data and the delivered lidar DEMs to expose offsets.

Listed in Table 2.7 are DOGAMI's quality control documents. The reader can follow hyperlinks in Appendix A to download the documents listed in both Tables 2.5 and 2.7.

Table 2.7: DOGAMI quality control documents

5/1/2012	DOGAMI	Summer Lake Thermal Infrared and Lidar Project, Quality Assurance Report
7/18/2012	DOGAMI	Paulina March Thermal Infrared and Lidar Project, Quality Assurance Report
7/18/2012	DOGAMI	OR Military Thermal Infrared and Lidar Project, Quality Assurance Report
7/18/2012	DOGAMI	Christmas Valley Thermal Infrared and Lidar Project, Quality Assurance Report
7/18/2012	DOGAMI	Baker Pass Thermal Infrared and Lidar Project, Quality Assurance Report

3.0 ACKNOWLEDGMENTS

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Oregon Department of Administrative Services	Stephani Tew

4.0 REFERENCES

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Madin, I.P., English, J.T., Ferro, P.A., and Niewendorp, C.A., 2013, Using Airborne Thermal Infrared and lidar imagery to search for geothermal anomalies in Oregon: Oregon Department of Geology and Mineral Industries ARRA Deliverable Report, p. 32. Accessed from http://www.oregongeology.org/sub/gtilo/data/supplemental/Using_Airborne_Thermal_Infrared.pdf

Niewendorp, C.A., 2013, Thermal gradient drilling: Oregon Department of Geology and Mineral Industries ARRA Deliverable Report, p. 24. Accessed from http://www.oregongeology.org/sub/gtilo/data/supplemental/ARRA_Well_Drilling_Report.pdf

Niewendorp, C.A. Ricker, T.R., Rabjohns, K.W., and Brodie, S.H., 2012, Geothermal Information Layer for Oregon, release 2 (GTILO-2): Oregon Department of Geology and Mineral industries Digital Data Series GTILO-2. Accessed from http://www.oregongeology.org/sub/gtilo/data/GTILO-Release-2.zip

APPENDIX A

Hyperlinks to TIR Project Documents

Hyperlink	Report
http://www.oregongeology.org/sub/gtilo/data/supplemental/TIR_RFP107-2888-11.pdf	RFP 107-2888-11, Georeferenced Airborne Thermal Infrared Imaging
http://www.oregongeology.org/sub/gtilo/data/supplemental/ARRA_NEPA.pdf	NEPA permit
http://www.oregongeology.org/sub/gtilo/data/supplemental/TIR_CV-OM-PM-BP_Report.pdf	Airborne Remote Sensing Thermal Infrared & Lidar: Summer Lake, Oregon; Delivery 1 v.2
http://www.oregongeology.org/sub/gtilo/data/supplemental/TIR_SummerLake.Report.pdf	Airborne Remote Sensing Thermal Infrared & Lidar: Christmas Valley, Oregon Military, Paulina Marsh, & Baker Pass, Oregon; Delivery 2 v.2
http://www.oregongeology.org/sub/gtilo/data/supplemental/TIR_SummerLake_QC.pdf	Summer Lake Thermal Infrared and Lidar Project, Quality Assurance Report
http://www.oregongeology.org/sub/gtilo/data/supplemental/ TIR_PaulinaMarsh_QC.pdf	Paulina March Thermal Infrared and Lidar Project, Quality Assurance Report
http://www.oregongeology.org/sub/gtilo/data/supplemental/TIR_ORMilitary_QC.pdf	OR Military Thermal Infrared and Lidar Project, Quality Assurance Report
http://www.oregongeology.org/sub/gtilo/data/supplemental/ TIR_ChristmasValley_QC.pdf	Christmas Valley Thermal Infrared and Lidar Project, Quality Assurance Report
http://www.oregongeology.org/sub/gtilo/data/supplemental/ TIR_BakerPass_QC.pdf	Baker Pass Thermal Infrared and Lidar Project, Quality Assurance Report