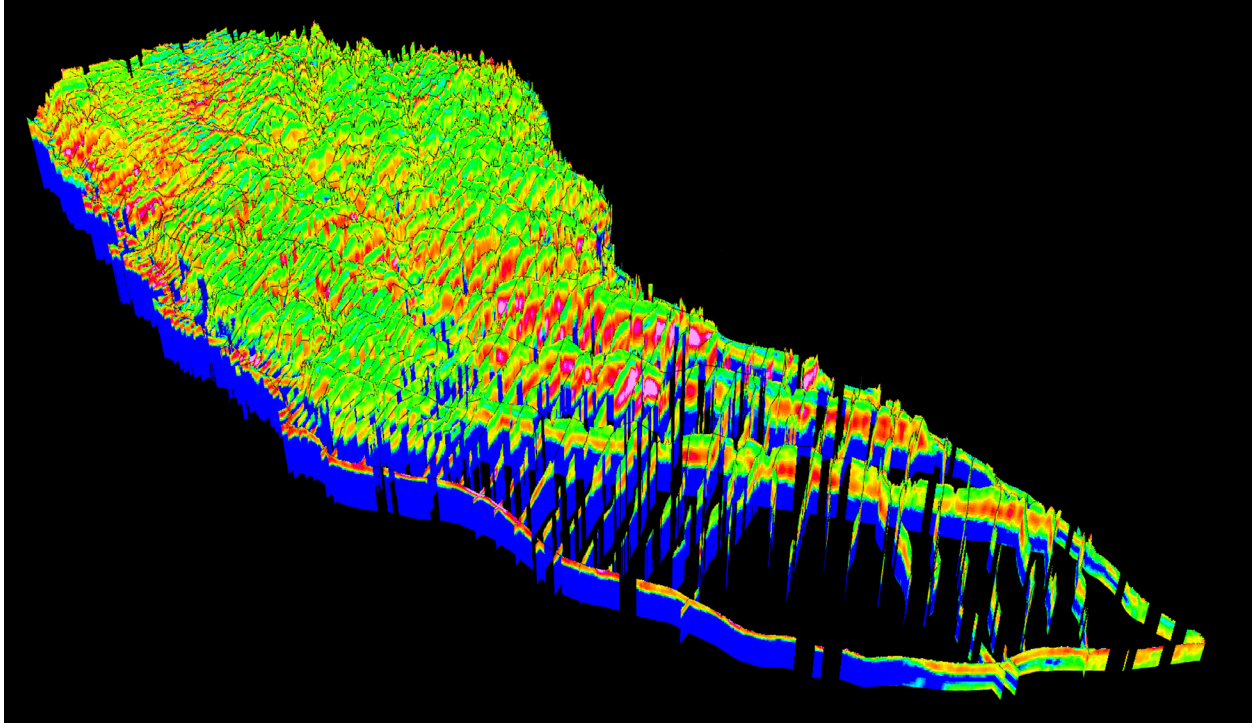


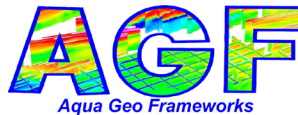
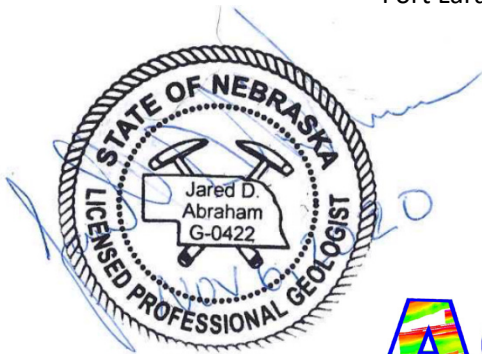
Final Spatially-Constrained Inversions Report and Data Delivery From the Airborne Electromagnetic Survey of a portion of the Middle Republican Natural Resources District



Jared D. Abraham NE PG # 0422
Principle Geophysicist/Geologist
(303) 905-6240

Theodore H. Asch, NE PG #0430
Research Geophysicist
(720) 415-7312

Aqua Geo Frameworks, LLC
10848 Ridge Road
Fort Laramie, WY 82212



November 6, 2020

1.0 Introduction

This survey included the acquisition, processing, and inversion of AEM data for a portion of the Middle Republican Natural Resources District (MRNRD). The data acquisition plan is presented in [Figure 1](#).

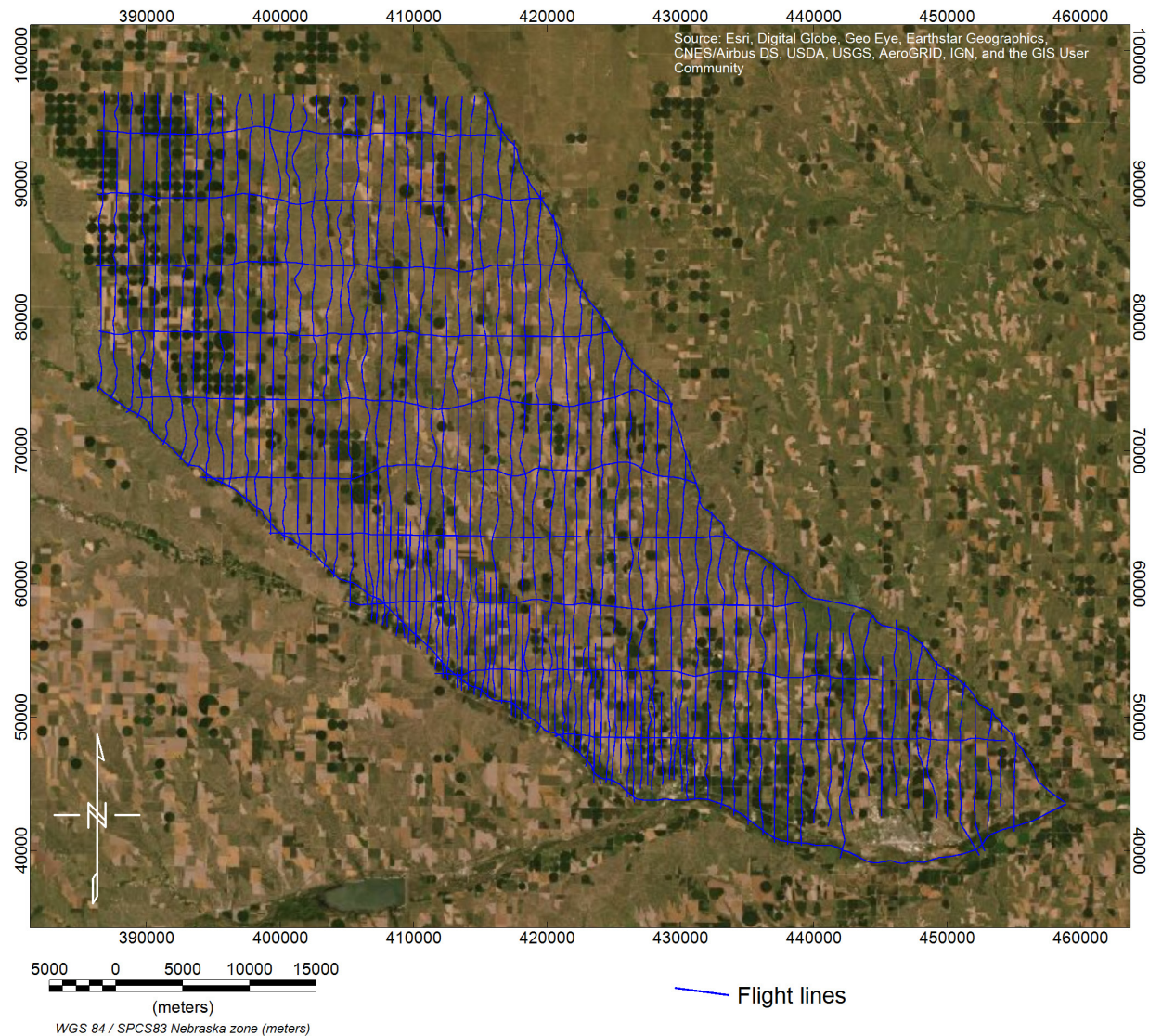


Figure 1. Planned AEM acquisition within a portion of the MRNRD displayed as blue lines on ESRI aerial image.

Disclaimer: AGF conducted this project using the current standards of the geophysical industry and used in-house quality control standards to produce this geophysical survey and products. The geophysical methods and procedures described in this report are applicable to the particular project objectives, and these methods have been successfully applied by AGF to investigations and projects of similar size and nature. However, field or subsurface conditions may differ from those anticipated, and the resultant data may not achieve the project objectives. AGF's services were performed consistent with the professional skill and care ordinarily provided by professional geophysicists under the same or similar circumstances. No other warranty or representation, either expressed or implied, is made by AGF in connection with its services unless in writing and signed by an authorized representative of AGF.

2.0 Schedule/Timeline

SkyTEM mobilized to Palisade, Nebraska on July 31, 2020. The system was assembled August 1-3, 2020 and ground tests were conducted. Production began on August 4, 2020 and continued through August 11, 2020. The system and crew demobilized from Palisade, Nebraska on August 12, 2020.

3.0 Data Acquisition Summary

The MRNRD data acquisition was flown out of a local farm near Palisade, Nebraska. Fourteen (14) production flights took place from August 4-11, 2020. Two production flights were flown on the 4th through 8th of August, three production flights on the 9th of August, and one production flight on the 11th of August. Line-km totals from each flight, and day are provided in [Table 3-1](#). 2716.9 line-km (1688.2 line-miles) of AEM data were acquired over the MRNRD area. [Figure 2](#) is an “as-flown” map view of the timing and spatial orientation of the flight lines, colored by data acquired. In some locations, the as-flown lines deviate from the planned lines due to infrastructure and safety as determined by the pilot.

Table 3-1. Flight line production by flight.

Date	Flight	Distance per Flight (km)	Distance per Day (km)	Distance per Day (miles)
8/4/2020	80402	181.1	265.1	163.6
	80404	84.0		
8/5/2020	80501	232.1	444.6	274.4
	80502	212.5		
8/6/2020	80602	210.5	421.1	259.9
	80603	210.6		
8/7/2020	80701	177.6	372.4	229.9
	80702	194.8		
8/8/2020	80801	189.9	419.5	259.0
	80802	229.6		
8/9/2020	80901	210.7	602.1	371.7
	80902	192.8		
	80903	198.5		
8/11/2020	81102	192.2	192.2	118.6
		Total:	2716.9 km	1677.1 miles

A map of the airborne platform’s flight height during data acquisition is presented in [Figure 3](#). Higher flight altitudes would be due to going over powerlines and other infrastructure that would need to be avoided by the pilot. In some instances, the steep canyons cannot be draped due to their width and the performance of the helicopter. The term “drape” refers to the maintaining of a constant height of the system above the topography. The typical specification is 30 meters and no adverse impact is caused when the system is flown between 20 to 40 meters. A consequence of higher flight altitudes can be a

degradation in the acquired data signal quality as the system gets farther from the subsurface targets of interest which cannot be avoided due to aircraft safety.

The speed is another factor to look at with regard to data coverage as the speed dictates the effective ground sampling. As the AEM system transmitter operates at programmed time intervals, the faster the system moves, the further apart the measurements are. [Figure 4](#) is a plot of the equivalent ground speed of the AEM system over the acquisition area.

The wind has the largest impact on the ground speed as the speed is slower into the wind and faster when traveling with the wind. This is caused by the pilot trying to keep the system as level as possible and maintaining a good drape over the ground. [Figure 5](#) and [Figure 6](#) are plots of the AEM system tilt in the X-direction (in the direction of travel) and the Y-direction (perpendicular to the direction of travel). Typically, the X-direction is subject to more changes due to changing wind speed and helicopter speed around obstacles and topographic features. Tilts of ± 10 degrees are compensated for in the inversion. Given the topography ([Figure 7](#)) of the AEM survey area, the data were successfully collected at industry-acceptable standards. To ensure that the elevation used in the project is constant for all the data sources (i.e. boreholes and AEM) a Digital Elevation Model (DEM) was constructed for the LLNRD survey. The data was downloaded from the National Elevation dataset (NED) located at the National Map Website ([U.S. Geological Survey, 2020](#)) at a resolution of 1 arc-second or approximately 100 ft.

The estimated amplitude of the power line noise intensity (PLNI) is presented in [Figure 8](#). The PLNI map is useful when investigating the impacts of powerlines on the data quality. While the 60 Hz powerline signals can have little impact on the Rx signal due to time-gating and proper filtering, the conductive wires that are used to transmit the power do cause EM coupling impacts on the data and those data need to be removed prior to inversion, a process known as “de-coupling”.

As part of the SkyTEM system a Total Field magnetometer is included in the data acquisition package. The magnetic field signal is useful for determining deep seated geological contacts and is also extremely valuable for locating intrusive bodies. However, the magnetic field is also sensitive to anthropogenic features that contain ferrous metal and so is also used in the electromagnetic decoupling process. A plot of the residual of the magnetic Total Magnetic Field (TMF) of the survey area (corrected for diurnal drift using a ground-based station and the IGRF) is presented in [Figure 9](#). Both geological structure and cultural features can be identified within the AEM survey area.

Middle Republican Natural Resources District SCI Final Inversion and Data Delivery Report

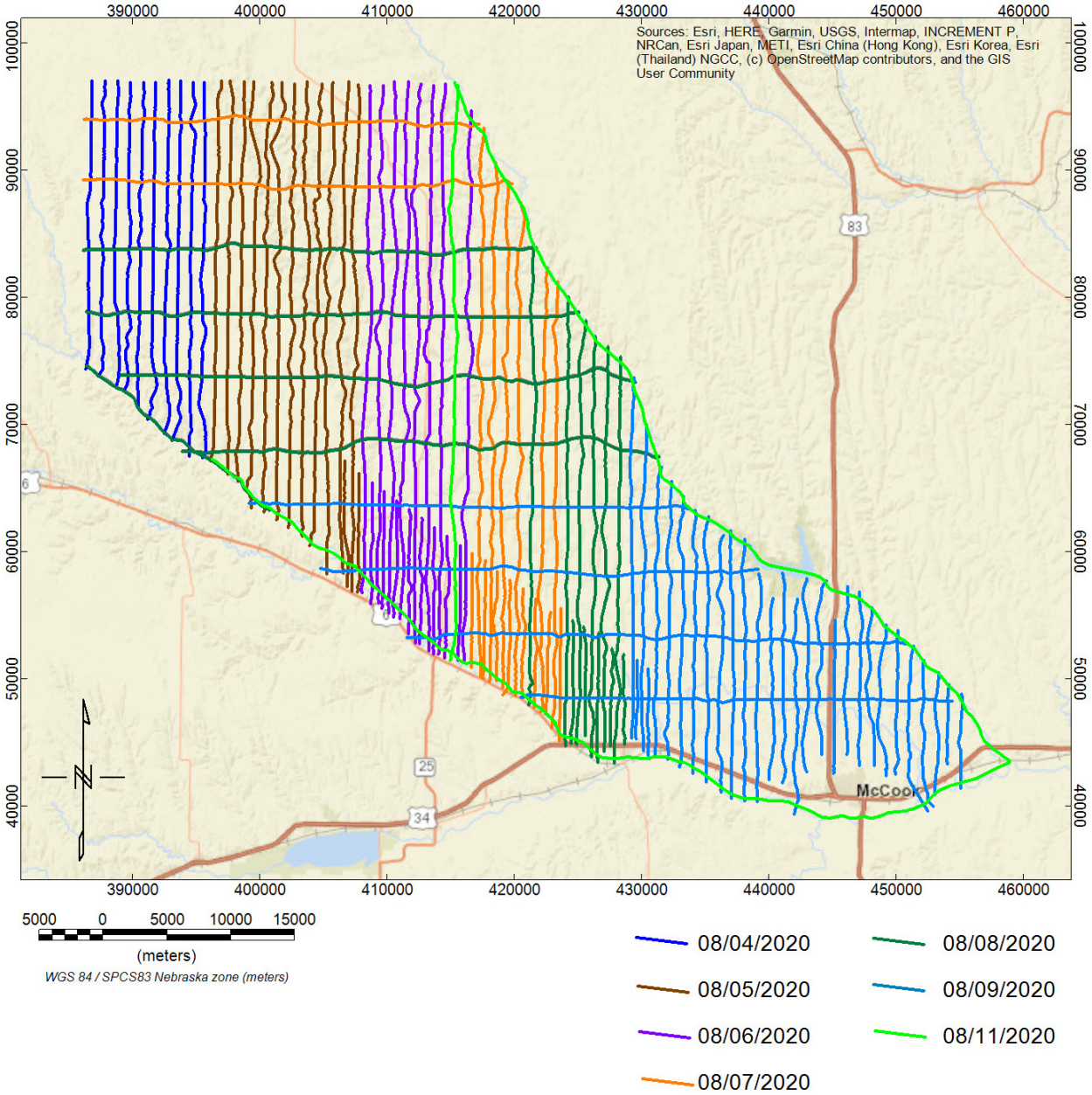


Figure 2. As-Flown map showing timing of the MRNRD AEM survey data acquisition. Shown on an ESRI roadmap.

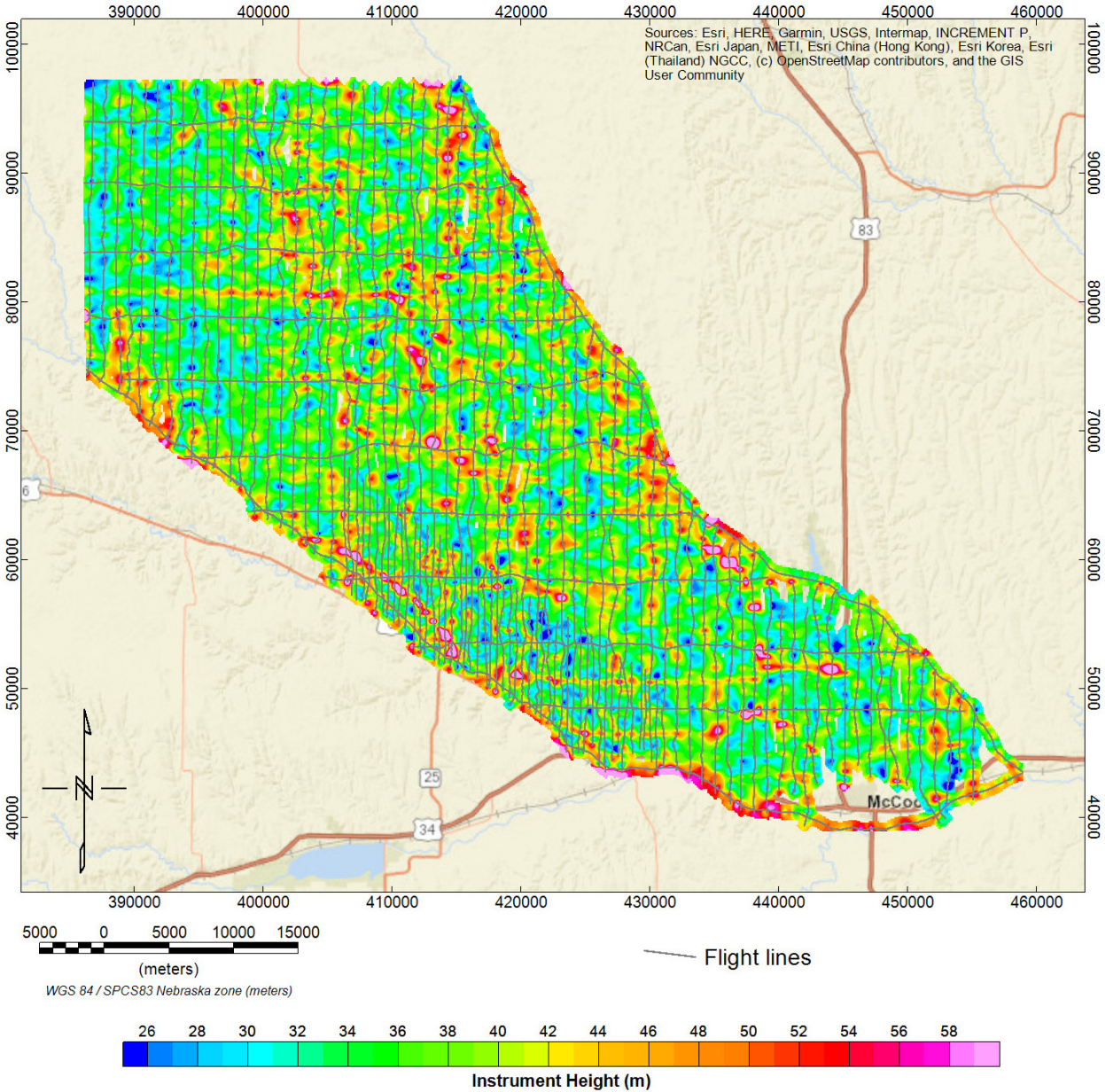


Figure 3. Map of the system height recorded during the MRNRD AEM survey, as-flown flight lines are indicated as grey lines. Shown on an ESRI roadmap.

Middle Republican Natural Resources District SCI Final Inversion and Data Delivery Report

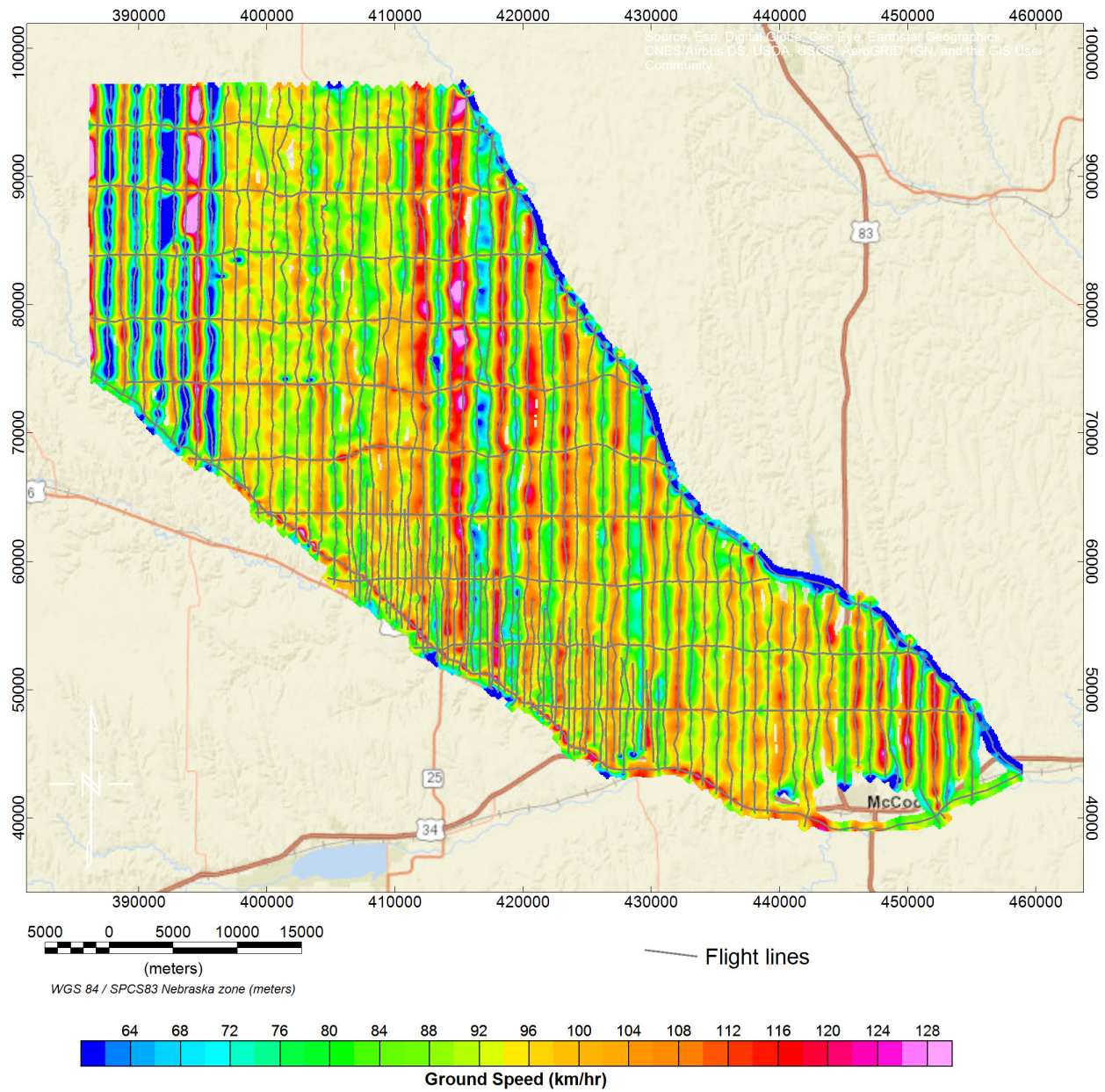


Figure 4. Map of the ground speed recorded during the MRNRD AEM survey; As-Flown flight lines are indicated as grey lines. Shown on an ESRI satellite image.

Middle Republican Natural Resources District SCI Final Inversion and Data Delivery Report

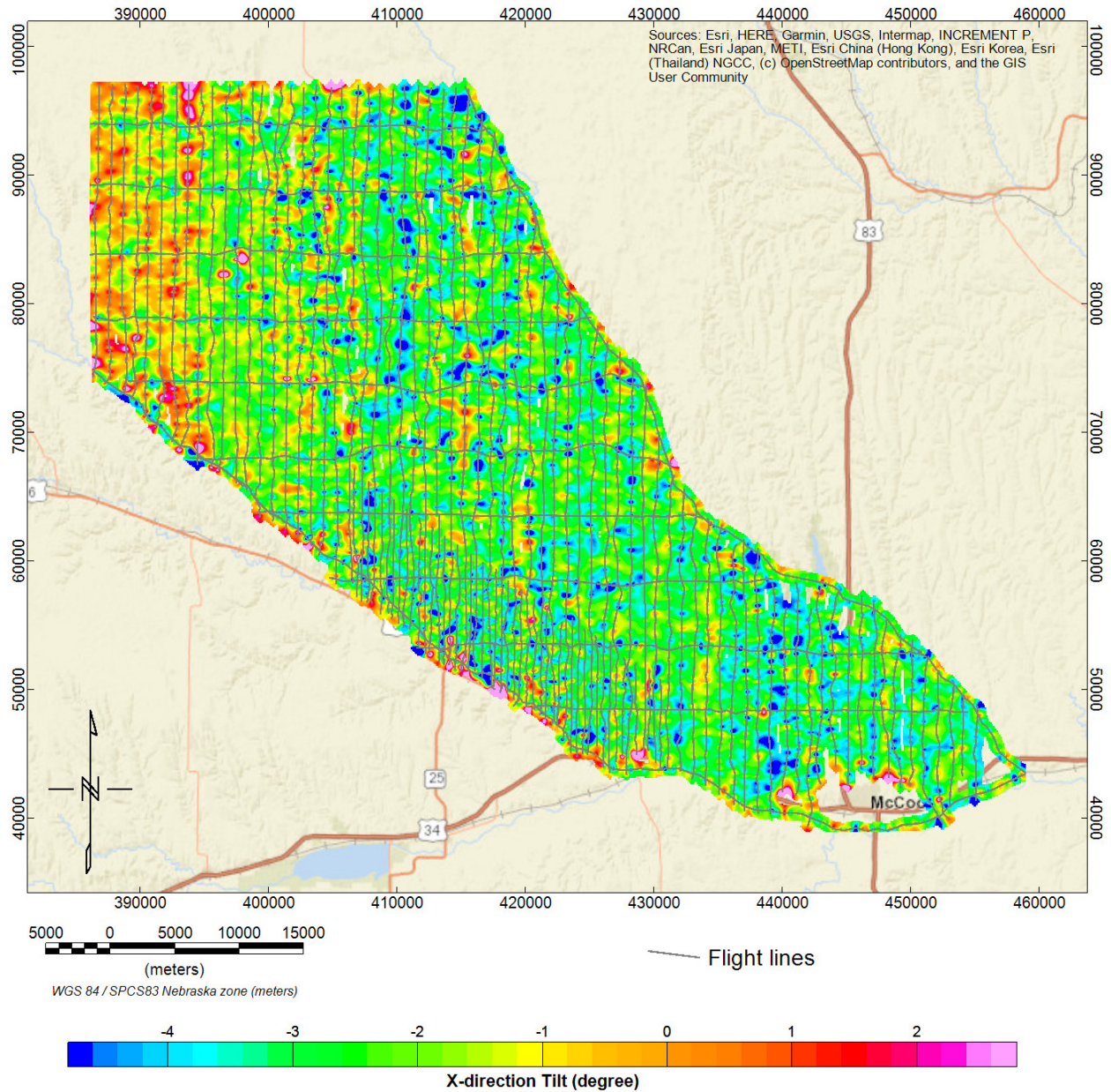


Figure 5. Map of the X-direction tilt recorded during the MRNRD AEM survey; As-Flown flight lines are indicated as grey lines. Shown on an ESRI roadmap.

Middle Republican Natural Resources District SCI Final Inversion and Data Delivery Report

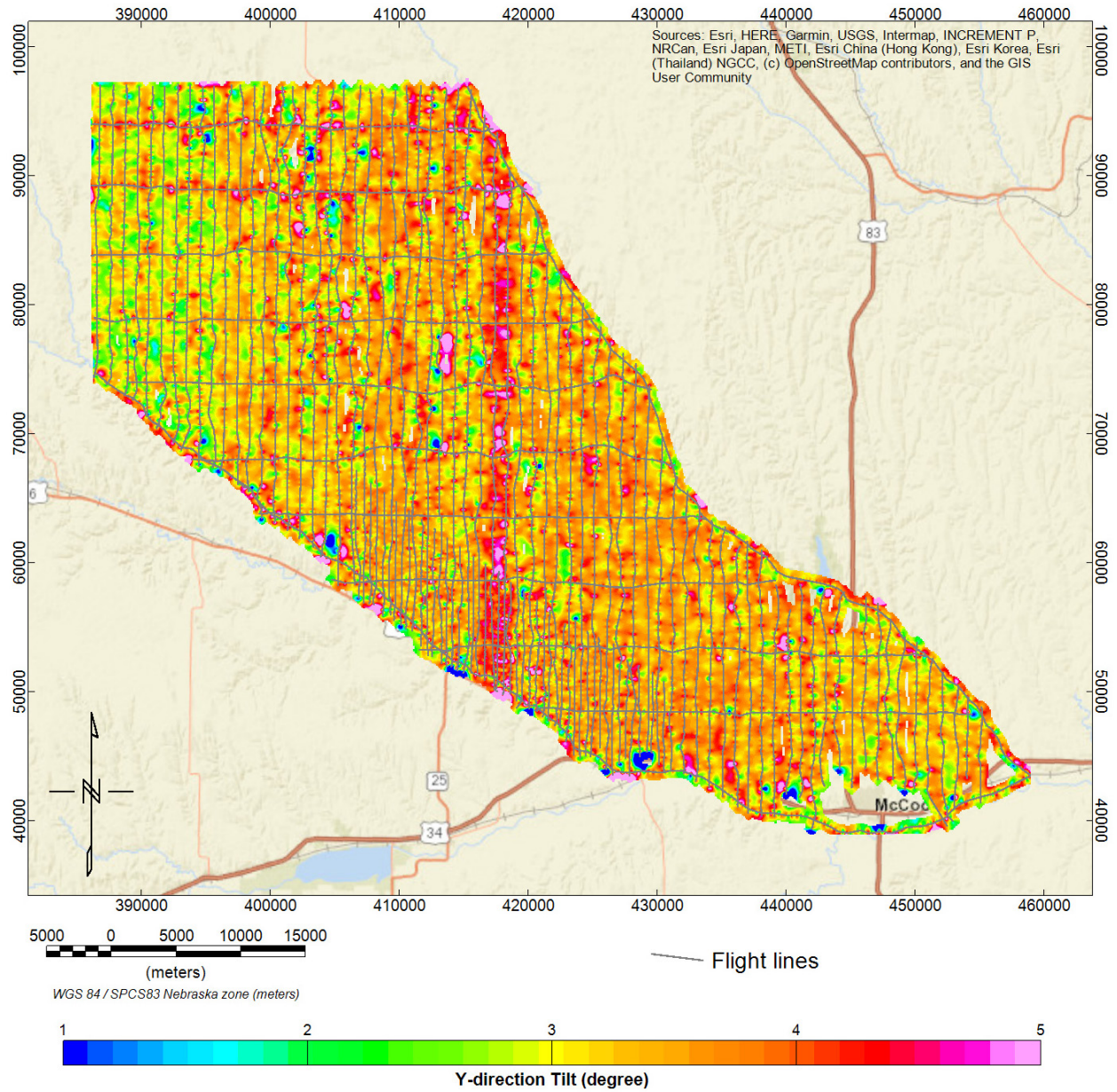


Figure 6. Map of the Y-direction tilt recorded during the MRNRD AEM survey, as-flown flight lines are indicated as grey lines. Shown on an ESRI roadmap.

Middle Republican Natural Resources District SCI Final Inversion and Data Delivery Report

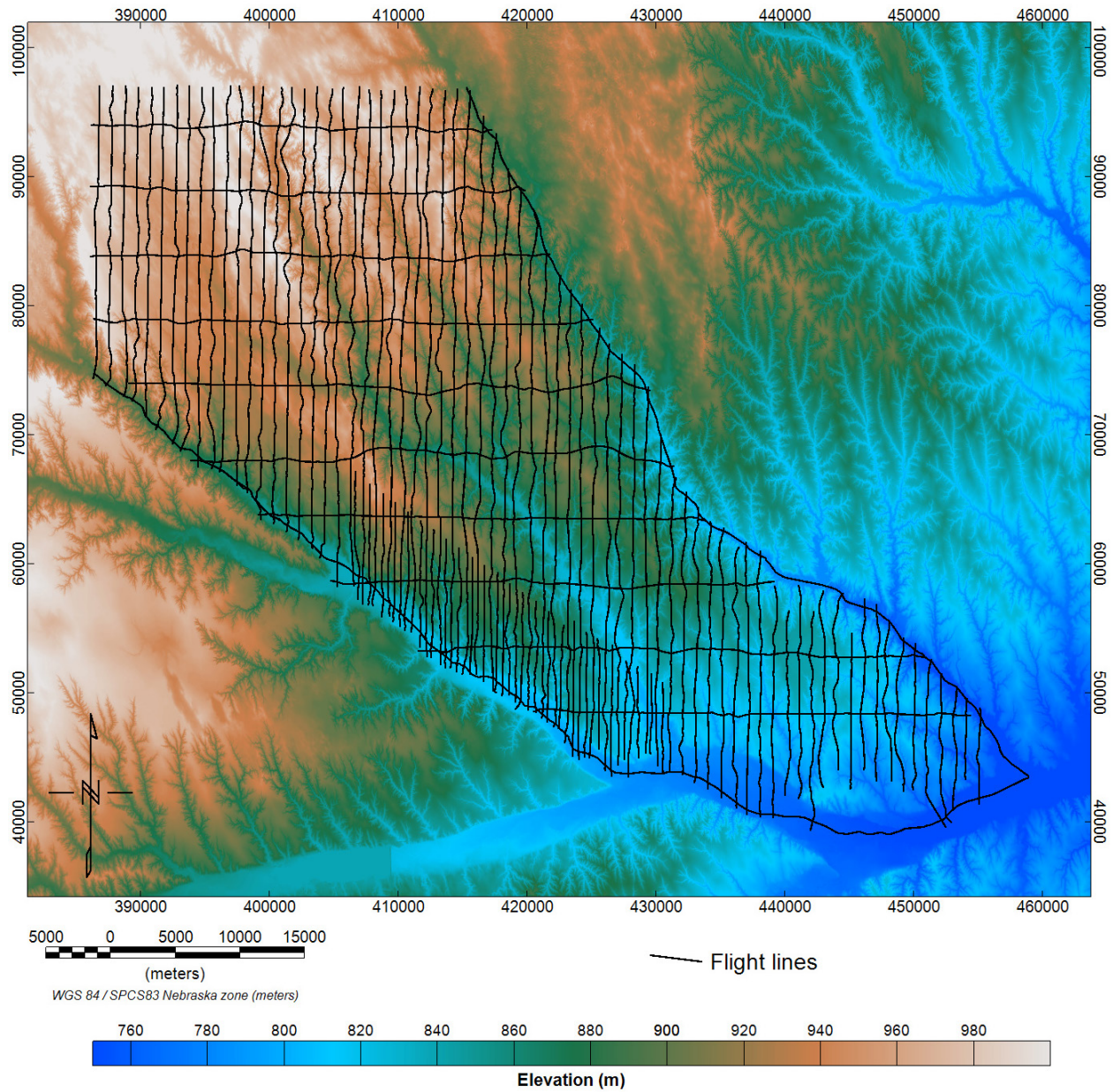


Figure 7. Map of the topography of the MRNRD AEM survey area; As-Flown flight lines are indicated as black lines.

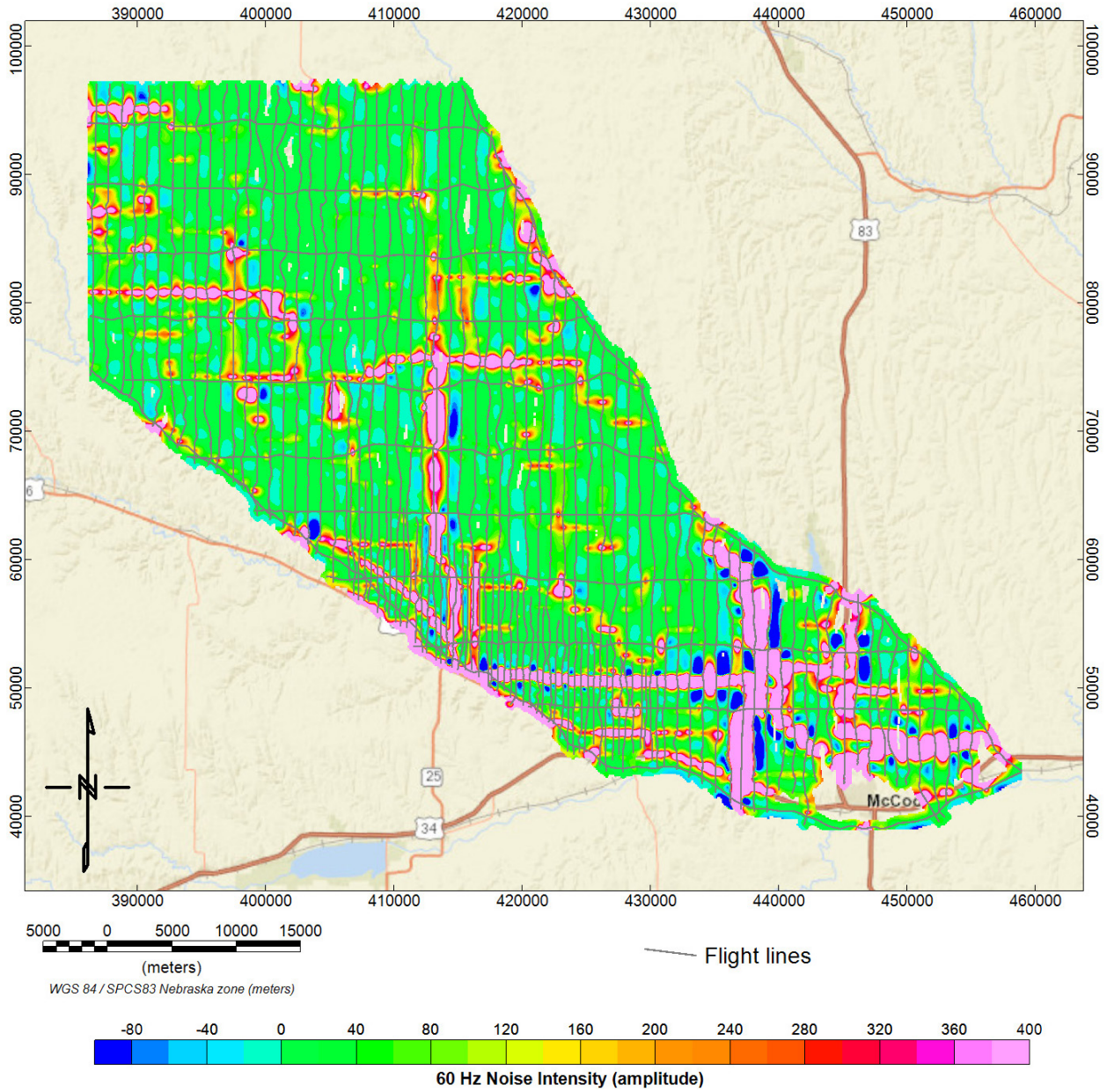


Figure 8. Power Line Noise Intensity (PLNI) for the MRNRD AEM survey area; As-Flown flight lines are indicated as grey lines. Shown on an ESRI roadmap.

Middle Republican Natural Resources District SCI Final Inversion and Data Delivery Report

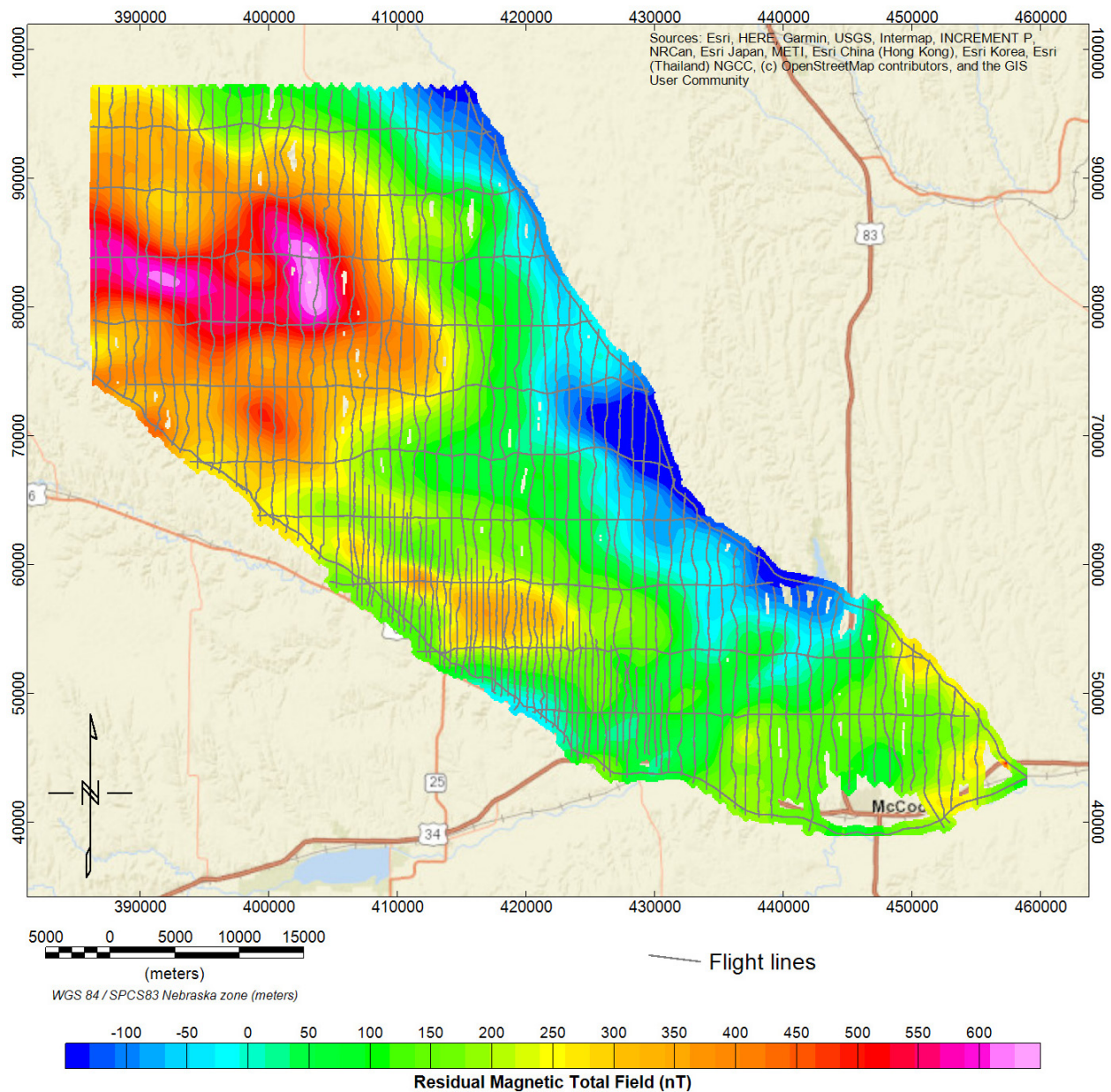


Figure 9. Residual magnetic Total Field strength for the MRNRD AEM survey area; As-Flown flight lines are indicated as grey lines. Shown on an ESRI roadmap.

4.0 Processing and Laterally- and Spatially-Constrained Inversions

4.1 Primary Field Compensation

A standard SkyTEM data acquisition procedure involves review of acquired raw data by SkyTEM for Primary Field Compensation (PFC) prior to continued data processing by AGF ([Schamper et al., 2014](#)). The primary field of the transmitter affects the recorded early time gates which, in the case of the LM, are helpful in resolving the near surface resistivity structure of the ground. The LM waveform is calculated and then used in the PFC correction to correct the early time gates.

4.2 Automatic Processing

The AEM data collected by the 304 were processed using Aarhus Workbench version 6.3.1.0 (at Aarhus Geosoftware (<http://www.aarhusgeosoftware.dk/aarhus-workbench-ib3ao>) described in [HydroGeophysics Group, Aarhus University \(2011\)](#)).

Automatic processing algorithms provided within the Workbench program are initially applied to the AEM data. DGPS locations were filtered using a stepwise, second-order polynomial filter of seven seconds with a beat time of 0.5 seconds, based on flight acquisition parameters. The AEM data are corrected for tilt deviations from level and so filters were also applied to both tilt meter readings with a median filter of three seconds and an average filter of two seconds. The altitude data were corrected using a series of two polynomial filters. The lengths of both eighth-order polynomial filters were set to 15 seconds with shift lengths of six (6) seconds. The lower and upper thresholds were 1 and 6 meters, respectively.

Trapezoidal spatial averaging filters were next applied to the AEM data. The times used to define the trapezoidal filters for the Low Moment were 1.0×10^{-5} sec, 1.0×10^{-4} sec, and 1.0×10^{-3} sec with widths of 7, 9, and 18 seconds. The times used to define the trapezoid for the High Moment were 1.0×10^{-4} sec, 1.0×10^{-3} sec, and 1.0×10^{-2} sec with widths of 10, 20, and 36 seconds. The trapezoid sounding distance was set to 1.0 seconds and the left/right setting, which requires the trapezoid to be complete on both sides, was turned on. The spike factor and minimum number of gates were both set to 25 percent for both soundings. Lastly, the locations of the averaged soundings were synchronized between the two moments.

4.3 Manual Processing and Laterally-Constrained Inversions

After the implementation of the automatic filtering, the AEM data were manually examined using a sliding two-minute time window. The data were examined for possible electromagnetic coupling with surface and buried utilities and metal ([Figure 8](#)), as well as for late time-gate noise. Data affected by these were removed. Areas were also cut out where the system height was flown greater than approximately 65 m (213 ft) above the ground surface which caused a decrease in the signal level ([Figure 3](#)).

The AEM data were then inverted using a Laterally-Constrained Inversion (LCI) algorithm ([HydroGeophysics Group Aarhus University, 2011](#)). The profile and depth slices were examined and any

remaining electromagnetic couplings were masked out of the data set. Vertical constraints on the resistivity were set at 2.7 and at 1.6 for the horizontal resistivity constraints with a reference distance of 100 m (328 ft).

Borehole data were gathered from both the Nebraska Department of Natural Resources (NE-DNR) and Nebraska School of Natural Resources Conservation and Survey Division (CSD). These boreholes were used in the QA/QC process to determine the system's calibration and ability to resolve the formations, geological units, and lithologies of interest. These do not serve as interpretations but only as checks in the acquisition and inversion process. [Figure 10](#) is a map of the location of the boreholes separated by NE-DNR or CSD. The boreholes that were used in the QA/QC and are from the CSD Nebraska Statewide Test Hole Database ([UNL, 2020a](#)), and CSD provided (personal communication Jesse Korus, Assistant Professor, CSD, June 2020) NE-DNR Registered Well Database ([NE-DNR, 2020](#))

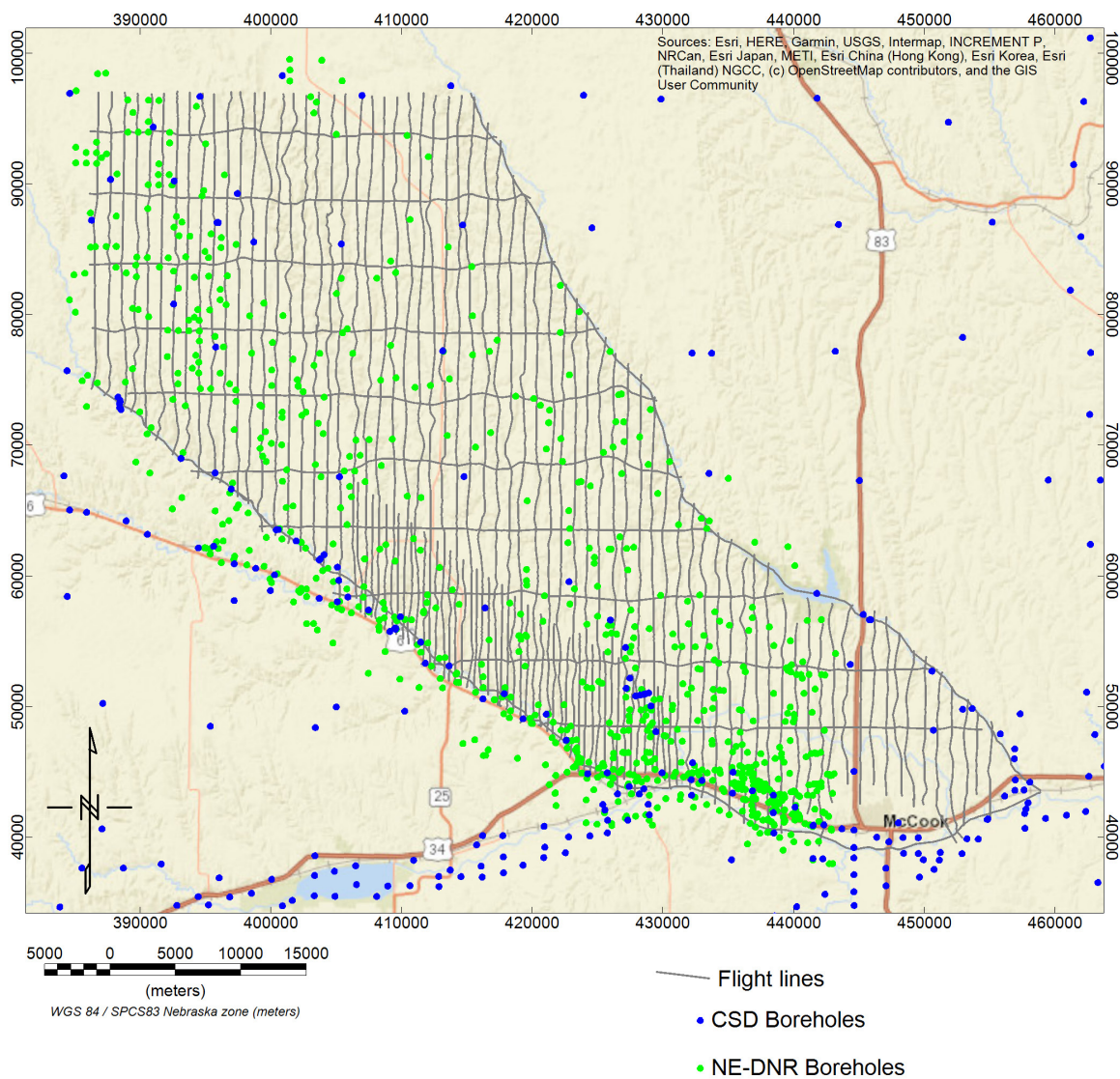


Figure 10. Map of the MRNRD flight lines (gray lines) with the Nebraska Department of Natural Resources (NE-DNR) and Conservations and Survey Division (CSD) boreholes indicated. Shown on an ESRI roadmap.

4.4 Spatially-Constrained Inversions

Following the initial decoupling and LCI analysis, Spatially-Constrained Inversions (SCI) were performed. SCIs use EM data along, and across, flight lines within user-specified distance criteria ([Viezzoli et al., 2008](#)).

The MRNRD data were inverted using SCI smooth models with 40 layers, each with a starting resistivity of 10 Ohm-m (equivalent to a 10 ohm-m halfspace). The thicknesses of the first layers of the models were about 6 ft with the thicknesses of the consecutive layers increasing by a factor of about 1.08. The depths to the bottoms of the 39th layers were set to 1,066 ft (325 m), with thicknesses up to about 93 ft (28 m). The thicknesses of the layers increase with depth ([Table 4-1](#)) as the resolution of the technique decreases. The spatial reference distance, s , for the constraints was set to 328 ft (100 m) with power law falloff of 0.75. The vertical and lateral constraints, **ResVerSTD** and **ResLatStd**, were set to 2.4 and 1.4, respectively, for all layers.

After final processing, 2,384.2 line-km (1,471.7 line-miles) of data were retained for the final inversions for the MRNRD survey. This amounts to a data retention of about 87.8%. This high retention percentage is due to the careful optimization of flight line design for the MRNRD AEM survey. An image of the comparison between the as-flown and the data retained for inversion is presented in [Figure 11](#).

In addition to the recovered resistivity models the SCIs also produce data residual error values (single sounding error residuals) and Depth of Investigation (DOI) estimates. The data residuals compare the measured data with the response of the individual inverted models ([Christensen et al., 2009](#)). The DOI provides a general estimate of the depth to which the AEM data are sensitive to changes in the resistivity distribution at depth ([Christiansen and Auken, 2012](#)). Two DOI's are calculated: a "Conservative" DOI at a cumulative sensitivity of 1.2 and a "Standard" DOI set at a cumulative sensitivity of 0.6. A more detailed discussion on the DOI can be found in [Asch et al. \(2015\)](#).

[Figure 12](#) presents a histogram of the MRNRD SCI inversion data/model residuals and a map of the data/model residuals for the MRNRD AEM study area is presented in [Figure 13](#). The histogram shows a good tight distribution of the inversion residuals with no obvious bias. The map of the residuals clearly shows the areas around the powerlines and the infrastructure are causing the increased noise in the inversions. Any residual below 1.0 is below the errors of the stacking of the raw AEM signals and is considered to be within the data error window. The areas above 1.0 are generally caused by increased noise from EM couplings, but area still usable as long as caution is exercised in interpretation of deeper structures.

Table 4-1. Thickness and depth to bottom for each layer, in meters and feet, in the Spatially Constrained Inversion (SCI) AEM earth models. The thickness of the model layers increase with depth as the resolution of the AEM technique decreases.

Layer	Depth to Bottom (ft)	Thickness (ft)	Depth to Bottom (m)	Thickness (m)	Layer	Depth to Bottom (ft)	Thickness (ft)	Depth to Bottom (m)	Thickness (m)
1	6.6	6.6	2.0	2.0	21	276.8	23.0	84.3	7.0
2	13.6	7.0	4.1	2.1	22	301.2	24.4	91.8	7.5
3	21.0	7.4	6.4	2.3	23	327.3	26.0	99.7	7.9
4	28.9	7.9	8.8	2.4	24	355.0	27.7	108.2	8.4
5	37.4	8.4	11.4	2.6	25	384.5	29.5	117.2	9.0
6	46.3	9.0	14.1	2.7	26	415.9	31.4	126.7	9.6
7	55.9	9.6	17.0	2.9	27	449.3	33.4	136.9	10.2
8	66.1	10.2	20.1	3.1	28	484.9	35.6	147.8	10.9
9	76.9	10.8	23.4	3.3	29	522.8	37.9	159.3	11.6
10	88.4	11.5	26.9	3.5	30	563.2	40.4	171.6	12.3
11	100.7	12.3	30.7	3.7	31	606.1	42.9	184.7	13.1
12	113.8	13.1	34.7	4.0	32	651.9	45.7	198.7	13.9
13	127.7	13.9	38.9	4.2	33	700.6	48.7	213.5	14.8
14	142.5	14.8	43.4	4.5	34	752.4	51.8	229.3	15.8
15	158.3	15.8	48.2	4.8	35	807.6	55.2	246.1	16.8
16	175.1	16.8	53.3	5.1	36	866.3	58.8	264.0	17.9
17	192.9	17.9	58.8	5.4	37	928.9	62.5	283.1	19.1
18	212.0	19.0	64.6	5.8	38	995.5	66.6	303.4	20.3
19	232.2	20.3	70.8	6.2	39	1066.4	70.9	325.0	21.6
20	253.8	21.6	77.3	6.6					

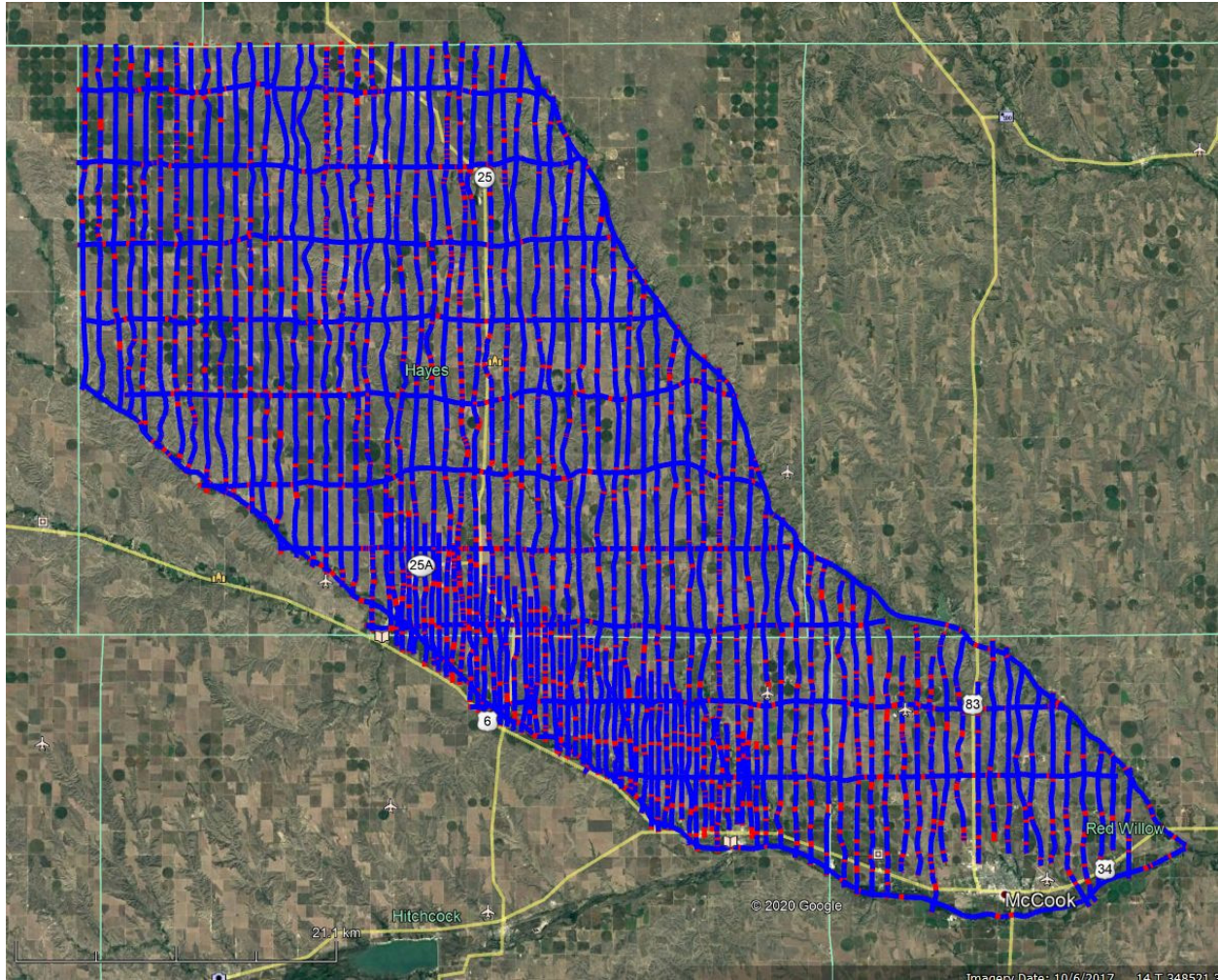


Figure 11. Locations of inverted data (blue lines) along the AEM flight lines (red lines) in the MRNRD survey area plotted with an ESRI aerial satellite background. Where blue lines are not present indicates decoupled (removed) data. These data are included as Google Earth KMZ files in Appendix 3.

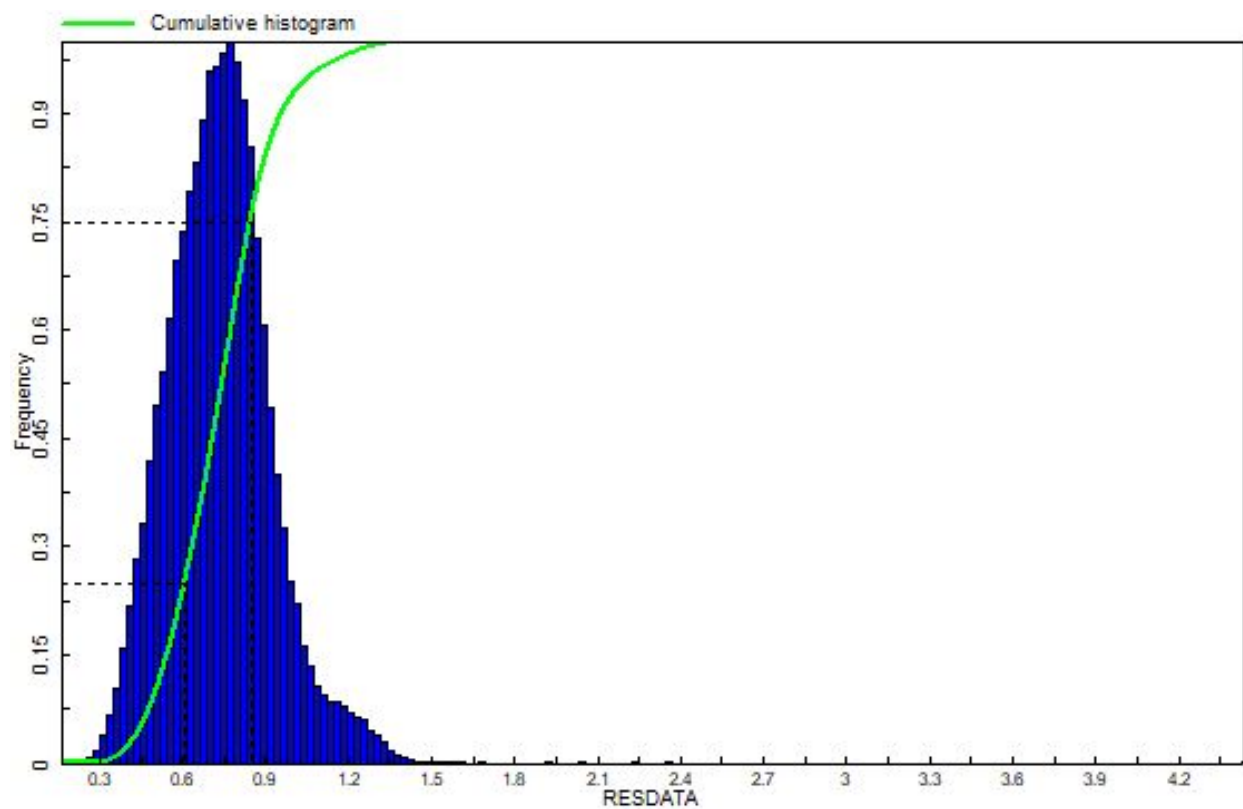


Figure 12. Data/model residual histogram for the MRNRD SCI inversion results.

Middle Republican Natural Resources District SCI Final Inversion and Data Delivery Report

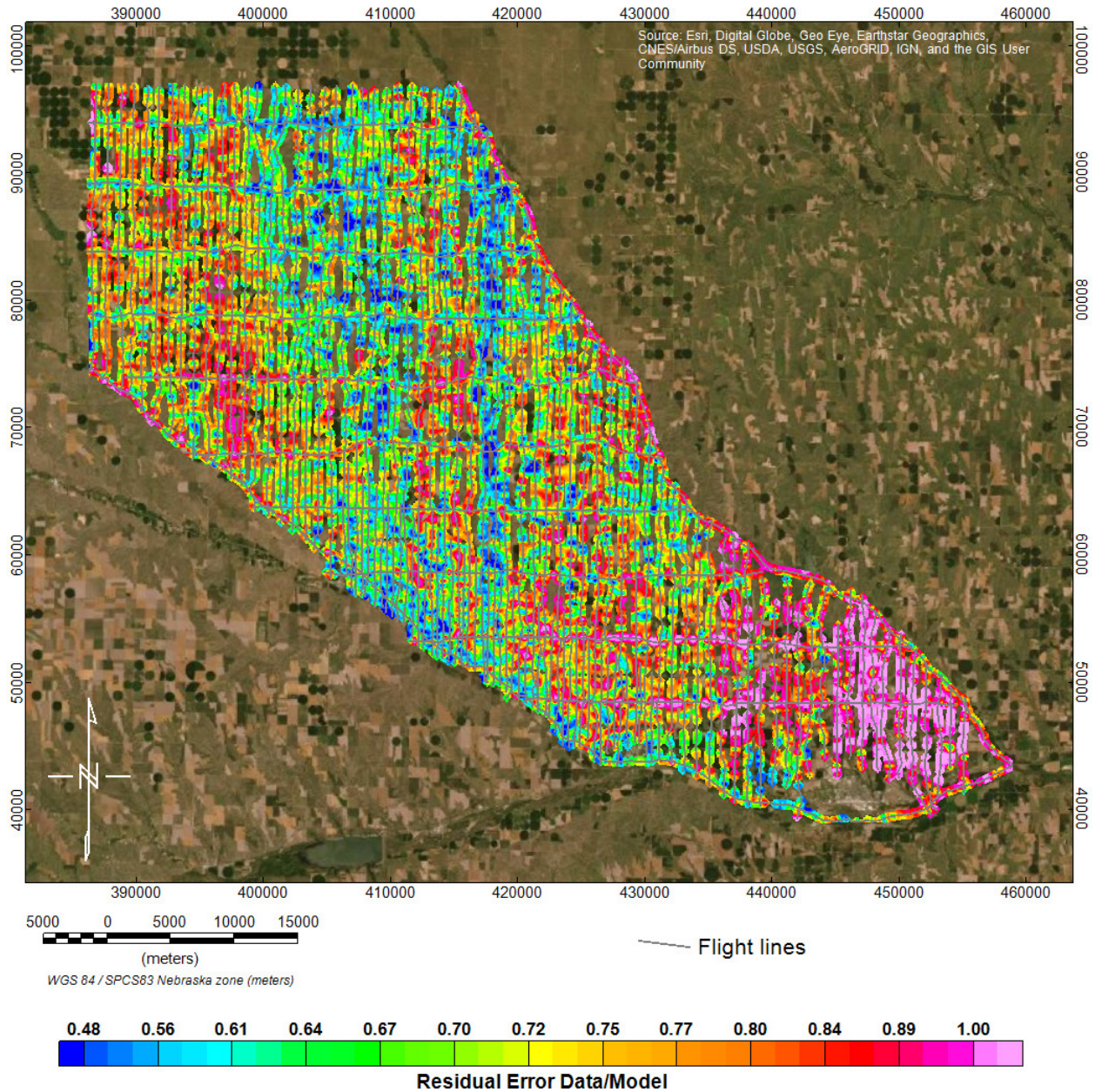


Figure 13. Map of data residuals for the MRNRD AEM SCI inversion results plotted with an Esri Satellite background. These data are included as a Google Earth KMZ file in Appendix 3. The residuals are high in the southeast part of the survey area where there were a large number of power lines coupling with the AEM system.

5.0 Profiles and 3D Images

Two-dimensional (2D) and three-dimensional (3D) images of the final SCI inversion results have been developed using Encom Profile Analyst ([DatamineDiscover, 2020](#)). Each profile has a small index map showing the location of the survey with the red line indicating the current profile being displayed. Also, included in the profile is the data residual from the SCI inversion as a line plot above the resistivity inversion profile. The color scale is in log-space and stretches from 10 to 100 ohm-m. Each profile is a unique length and the profiles are fitted with the size of the profile page. Examples of east-west and north-south lines are presented in [Figure 14](#) (east-west 2D profile L200409) and [Figure 15](#) (north-south 2D profile L102301). Boreholes are plotted on the figures that were used in the QA/QC and are from the CSD Nebraska Statewide Test Hole Database ([UNL, 2020a](#)), and CSD provided (personal communication Jesse Korus, Assistant Professor, CSD, June 2020) Nebraska Department of Natural Resources (NE-DNR) Registered Well Database ([NE-DNR, 2020](#)) and are plotted when they are within 500 meters of the flight line. On curved lines the projection line is from the ends of the flight line and may not accurately reflect the 500-meter projection distance. The lithology color scale is from the recommendation from the Nebraska Geocloud ([UNL, 2020b](#)). General geological units are pointed out in the figures to give the reader a sense of the interpretive process. There is good match between the coarse zones in the lithology logs to increased resistivity. 3D fence diagrams were constructed from the 2D profiles using a vertical exaggeration of 1:10. An example 3D fence diagram is presented in [Figure 16](#) with a view to the north with the same color range as used in the 2D Profiles.

Inspection of the profile indicates that the SkyTEM system was performing within specification and the inversions were successful. Further interpretation will occur in the future as part of a University of Nebraska Conservation Survey Division led project. The Middle Republican Natural Resources District AEM survey area is characterized by conductive to resistive materials of Quaternary (**Q**) with resistivities ranging from approximately 20 to 500 ohm-m. These **Q** deposits are overlaying the Tertiary Ogallala Group (**To**) with relatively resistive materials ranging from 15 to 100 ohm-m. Care will need to be used to separate out the **Q** from the **To** using boreholes and geological knowledge of the area. The basement of the area is predominantly Cretaceous Pierre Shale (**Kp**) with low resistivities on the order of 3-15 ohm-m. This provides both a hydrogeological as well as a geophysical basement in the area. On the far eastern end of the survey area it appears that the **Kp** is eroded off and the basement is the more resistive Cretaceous Niobrara Formation (**Kn**) with resistivities in the range of 20-40 ohm-m. Below the **Kn** there appears to be a low resistivity unit that may be the Cretaceous Carlile Shale (**Kc**). However, it is below the Depth of Investigation (DOI) as indicated by the gray dashed lines. [Figure 17](#) is a zoom of the eastern portion of line L201216 showing the edge of the **Kp**, the **Kn** and possible lower **Kc**. The basic geology and hydrology are summarized in [Korus and Howard \(2019\)](#). They provide the original references to the geological mapping in the area.

The complete collection of the 2D SCI profiles are contained in Appendix 1 and the 3D fence diagrams, viewed from multiple angles, are contained in Appendix 2. Both can be found at the following DropBox link:

https://www.dropbox.com/sh/81t0ql9lt55s3ax/AACb0uuYj_W1sg3y1fNTTXlCa?dl=0

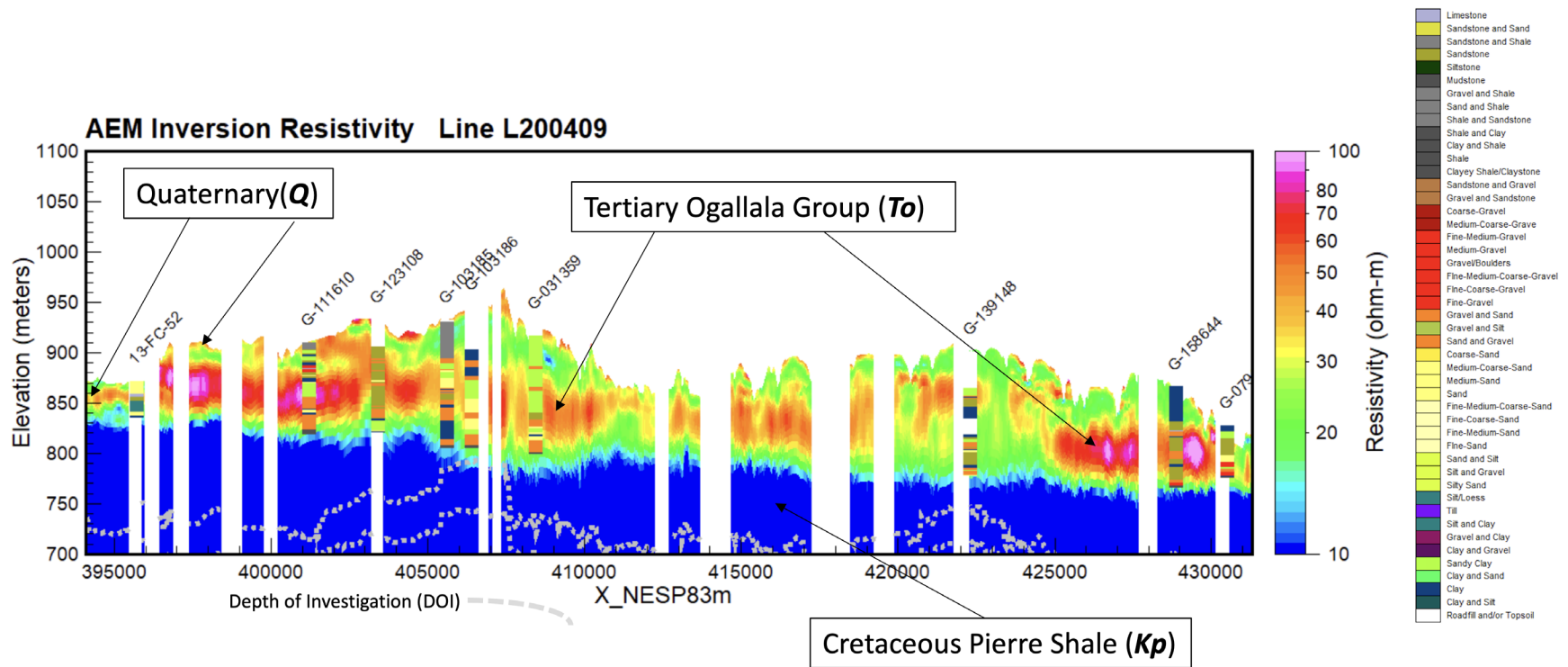


Figure 14. Example of 2D profile displaying the final SCI results of the MRNRD AEM survey along an approximately east-west flight line, L200409. The resistivity color scale is on the right side of the profile. The MRNRD SCI inversion results plotted as 2D profiles are included in Appendix 1.

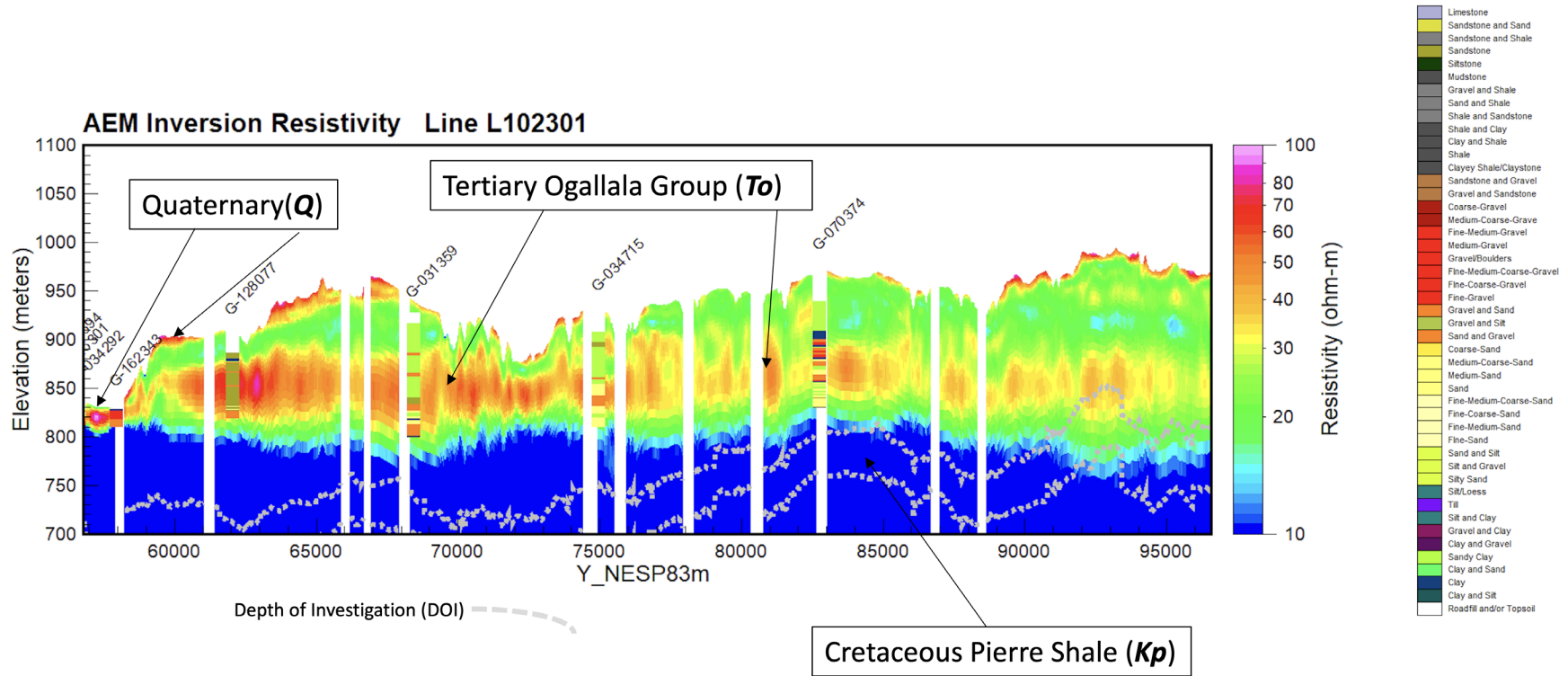


Figure 15. Example of 2D profile displaying the final SCI results of the MRNRD AEM survey along a north-south flight line, L102301. The resistivity color scale is on the right side of the profile. The MRNRD SCI inversion results plotted as 2D profiles are included in Appendix 1.

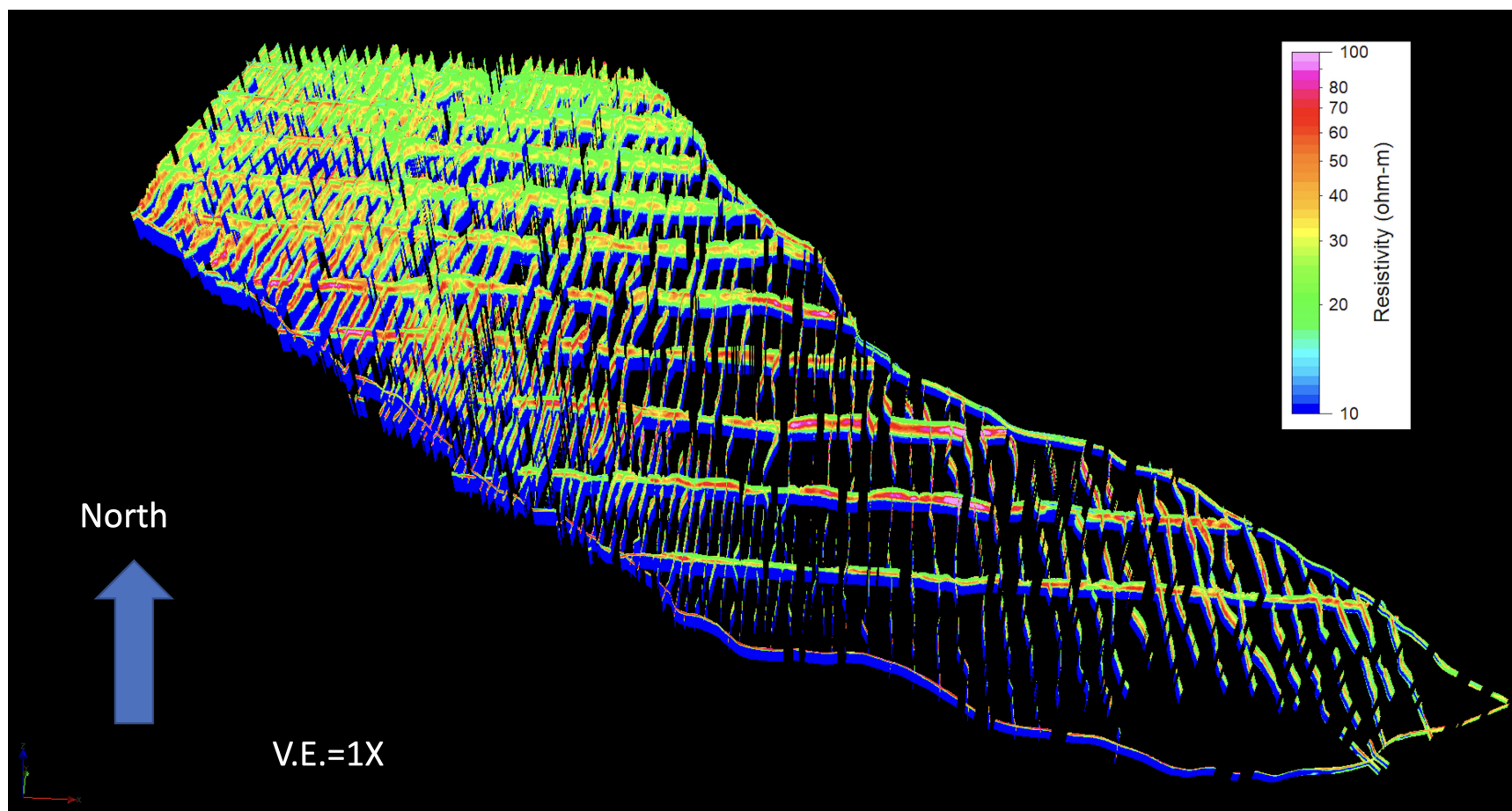


Figure 16. Example of 3D fence diagram displaying the final SCI results of the MRNRD AEM survey. The view is to the north. The color scale is the same as for the profiles. The MRNRD SCI inversion results plotted as 3D fence diagrams are included in Appendix 2.

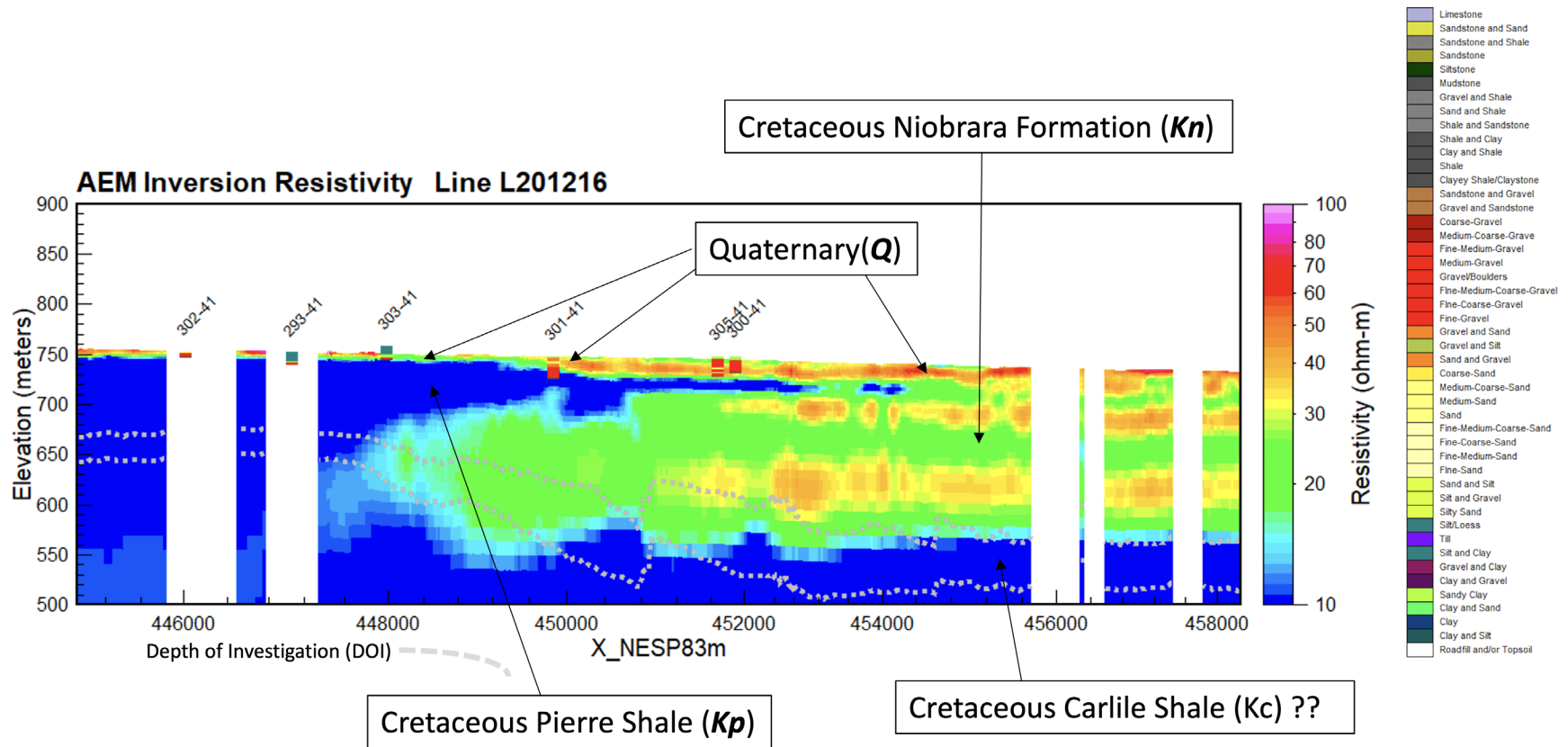


Figure 17. A zoom of the eastern portion of line L201216 showing the edge of the Cretaceous Pierre Shale (*Kp*), the Cretaceous Niobrara Formation (*Kn*), and possible lower Cretaceous Carlile Shale (*Kc*).

6.0 Summary

This report presents the final Spatially-Constrained Inversions for the AEM survey of selected areas of the Middle Republican Natural Resources District as 2D resistivity profiles and as 3D fence diagrams. In addition, the processed data and the SCI inversion results are presented as ASCII xyz files. Google Earth KMZ files of the As Flown flight lines, the data retained for inversion, and the inverted residual data model error have also been provided. All the raw SkyTEM data are included with the Aarhus Geosoft Workbench v.6.3.1.0 Workspace Files that are included in the deliverable as Workbench session WB_MRNRD2020_CSD. In addition, a GeoScene3D Project has been created to facilitate the interpretation of the inversions by CSD. A link to the DropBox location of these data files is presented above.

As discussed on previous occasions, we believe that these results provide a good, solid starting point for development of a hydrogeologic framework in the Middle Republican Natural Resources District AEM survey area.

7.0 Deliverables

[Table 7-1](#) describes the raw data files included in the zip file in Appendix-3_Deliverables \From_SkyTEM\ that were delivered by SkyTEM. As discussed above, fourteen (14) flights were required to acquire the 2020 MRNRD AEM data ([Figure 2](#)). Grouped by flight date, there are five (5) native-format data files included in the zip file in

01_RawData Appendix-3_Deliverables\From_SkyTEM\SkyTEM_20201003_MRNRD for each flight. These files have extensions of “*.sps” and “*.skb”. The “*.sps” files include navigation and DGPS location data and the “*.skb” files include the raw AEM data that have been PFC-corrected (discussed in [Section 4.1](#)). Two additional files are used for all the flights. These are the system description and specifications file (with the extension “*.gex”) in the GEO_SR2 subdirectory and the ‘mask’ file (with the extension “*.lin”), in the MASK subdirectory, which correlates the flight dates, flight numbers, and assigned line numbers. The original gex and lin files were slightly modified prior to import of the raw skb data. The modified versions are discussed below.

[Table 7-2](#) describes the data columns in the ASCII EM_MAG *.xyz files for the MRNRD 2020 AEM survey area. This file, MRNRD_20016_SkyTEM_EM_Mag_Aux_20201103.zip contains a Excel csv file with the electromagnetic raw data plus the magnetic and navigational data as supplied from SkyTEM.

[Table 7-3](#) lists the processed and edited AEM data used in the SCI inversion.

MRNRD_SCI04_MOD_dat.xyz is a file exported from the Aarhus Workbench from the final SCI inversion run. Each sounding consists of two rows of this table. The first being the Low Moment data and the second row being the High Moment data, which may be noted in the FID, RECORD, and SEGMENT columns. The FID and RECORD columns indicate the sounding number. The SEGMENT column indicates which channel (LM-1, HM-2) the data line refers to. Note also that the X and Y are the same for both the LM and HM. Line 24 in the header of the MRNRD_SCI04_MOD_dat.xyz data file lists the time gates, in

seconds, that match up with the dB/dt DATA array listed in [Table 7-2](#). This file along with a Geosoft gdb is located in Appendix-3_Deliverables\ProcessedData.

The final SCI inversion results, MRNRD_SCI04_MOD_inv.gdb and xyz, are delivered as both Geosoft “gdb” and ASCII “xyz” files. The data columns of these databases are described in [Table 7-4](#) (SCI) and are included in Appendix-3_Deliverables\SCI_Results.

In addition, Google Earth KMZ files of the As Flown flight lines, the data retained for inversion, and the SCI residual data errors. These KMZ’s can be found in Appendix 3 – Deliverables\KMZs.

In the Appendix-3_Deliverables is the folder MRNRD_AarhusWorkBench_WorkSpace that contains a zip file created by 7-Zip of the Aarhus Geosoftware Workspace used to process and invert the data, WB_MRNRD2020_CSD. The folder contains a zip file of the Workspace and system description GEX and production LIN (lists the times and flight lines) files that were slightly modified prior to importation of the raw skb data. The changes made were the LoopType changed from 73 to 72, the CalculateRawDataSTD changed from 1 to 0, and the LM RemoveInitialGates changed from 7 to 2.

A data report provided by SkyTEM describing the MRNRD2020 AEM survey and associated NNRD and PMNRD surveys’ system acquisition parameters is also included in Appendix-3_Deliverables under SkyTEM_Report. The format of what is in the Appendix-3_Deliverables\From_SkyTEM folder is listed in [Table 7-5](#).

AGF has also included an I-GIS GeoScene3D project ([Table 7-6](#)) containing the DEM and the AEM data for the MRNRD. The project was built using GeoScene3D version 12.0.0.657. This was included to expedite the use of this data by CSD and other users of I-GIS GeoScene3D.

In summary, the following are included as deliverables:

- Raw Data Files - SkyTEM files *.gex, *.skb, *.lin
- Processed data used in the SCI inversion as Geosoft database and ASCII *.xyz
- SCI results including Geosoft database and ASCII *.xyz files
- Google Earth KMZ files of AsFlown, Retained, and ResData
- Aarhus Geosoftware Workbench Version 6.3.1 WB_MRNRD2020_CSD Workspace
- The SkyTEM delivery to AGF including all files and report
- IGIS GeoScene 3D project

Table 7-1. Raw SkyTEM data files

Folder	File Name	Description
Data	..NavSys.sps, ...PaPc.sps, ...RawData_PFC.skb, ...DPGS.sps	Raw data files included for each flight used in importing to Aarhus Workbench
Geo	*.gex, SR2.gex & SR2.sr2.	SkyTEM304 System Description
Mask	*.lin	Production file listing dates, flights, and assigned line numbers

Table 7-2. Raw Data - Channel name, description, and units for MRNRD_20016_SkyTEM_EM_Mag_Aux_20201103.xyz with EM, magnetic, DGPS, Inclinator, altitude, and associated data.

Parameter	Description	Unit
Line	Line Number	
X_UTM14Nm	Easting, WGS84 UTM Zone 14N	Meters [m]
Y_UTM14Nm	Northing, WGS84 UTM Zone 14N	Meters [m]
X_NESP83m	Easting, Nebraska State Plane NAD83	Meters [m]
Y_NESP83m	Northing, Nebraska State Plane NAD83	Meters [m]
DEM_M	Digital Elevation	Meters [m]
Fid	Unique Fiducial Number	
Flight	Name of Flight	yyyymmdd.ff
DateTime	DateTime Format	Decimal days
Date	DateTime Format	yyyymmdd
Time	Time UTC	hhmmss.sss
AngleX	Angle (in flight direction)	Degrees
AngleY	Angle (perpendicular to flight direction)	Degrees
Height	Filtered Height Measurement	Meters [m]
Lon	Longitude, WGS84	Decimal Degrees
Lat	Latitude, WGS84	Decimal Degrees
Alt	DGPS Altitude above sea level	Meters [m]
GDSpeed	Ground Speed	Kilometers/hour [km/h]
Curr_LM	Current, Low Moment	Amps [A]
Curr_HM	Current, High Moment	Amps [A]
LMZ_G01 [Gates 0-27]	Normalized (PFC-Corrected) Low Moment Z-RxCoil value	pV/(m ⁴ *A)
HMZ_G01 [Gates 0-36]	Normalized (PFC-Corrected) High Moment Z-RxCoil value	pV/(m ⁴ *A)
HMX_G01 [Gates 0-36]	Normalized (PFC-Corrected) High Moment X-RxCoil value	pV/(m ⁴ *A)
_60Hz_Intensity	Power Line Noise Intensity monitor	
TMI	Total Field Magnetic field Intensity	nanoTesla [nT]
MAG_Raw	Corrected Total Magnetic Field Intensity	nanoTesla [nT]
Base_Mag	Raw Base Station Mag Data filtered	nanoTesla [nT]
Diurnal	Diurnal Drift corrections	nanoTesla [nT]
RMF	Residual Magnetic Field	nanoTesla [nT]
IGRF	International Geomagnetic Reference Field	nanoTesla [nT]
INC	Magnetic field inclination	Degrees
DEC	Magnetic field declination	Degrees

Table 7-3. Processed Data Used in Inversion - Channel name, description, and units for MRNRD_SCI04_MOD_dat.xyz and gdb data files.

Parameter	Description	Unit
LINE_NO	Line Number	
UTMX	Easting WGS84, UTM Zone 14	Meters [m]
UTMY	Northing WGS84, UTM Zone 14	Meters [m]
TIMESTAMP	Date Time Format	Decimal days
FID	Unique Fiducial Number	
RECORD	Data record number, in two's	
ELEVATION	Recorded topography from system GPS	Meters [m]
ALT	Altitude of system above ground	Meters [m]
INVALT	Inverted Altitude of system above ground	Meters [m]
INVALTSTD	Inverted Altitude Standard Deviation of system above ground	Meters [m]
DELTAALT	Change in Altitude of system above ground	Meters [m]
TILT	Not used, DUMMY 9999	
INVTILT	Not used, DUMMY 9999	
INVTILTSTD	Not used, DUMMY 9999	
NUMDATA	Number of data in record	
SEGMENT	Waveform segment number	
RESDATA	Residual of individual sounding	
RESTOTAL	Total residual for inverted section	
DATA[0] THROUGH DATA[48]	dB/dt data for each channel	V/(A*m**4)
DATASTD[0] THROUGH DATASTD[48]	Standard Deviation for dB/dt data for each waveform resistivity error per layer	

NOTE: Line 24 in the header of the MRNRD_SCI04_MOD_dat.xyz data file lists the time gates, in seconds, that match up with the dB/dt DATA array listed in [Table 7-3](#).

Table 7-4. Inversion Results - Channel name, description, and units for SCI_Results\MRNRD_SCI04_MOD_inv.gdb and xyz.

Parameter	Description	Unit
LINE	Line Number	
X_UTM14Nm	Easting WGS84, UTM 14N	Meters [m]
Y_UTM14Nm	Northing WGS84, UTM 14N	Meters [m]
X_NESP83m	Easting, Nebraska State Plane NAD83	Meters
Y_NESP83m	Northing, Nebraska State Plane NAD83	Meters
ELEVATION_M	DEM from MRNRD_DEM_SRFv6	Meters [m]
TOPO	Measured platform elevation	Meters (m)
FID	Unique Fiducial Number	
TIMESTAMP	Date Time Format	Decimal days
ALT	Altitude of system above ground	Meters [m]
INVALT	Inverted Altitude of system above ground	Meters [m]
INVALTSTD	Inverted Altitude Standard Deviation of system above ground	Meters (m)
RESDATA	Residual of individual sounding	
RESTOTAL	Total residual for inverted section	
RHO[0] THROUGH RHO[38]	Inverted resistivity of each layer	Ohm-m
RHO_STD[0] THROUGH RHO_STD[38]	Inverted resistivity error per layer	
DEP_TOP[0] THROUGH DEP_TOP[38]	Depth to the top of individual layers	Meters (m)
DEP_BOT[0] THROUGH DEP_BOT[38]	Depth to the bottom of individual layers	Meters (m)
THK[0] THROUGH THK[38]	Thickness of individual layers	Meters (m)
DOI_UPPER	More conservative estimate of DOI (CumSens=1.2)	Meters (m)
DOI_LOWER	Less conservative estimate of DOI (CumSens=0.6)	Meters (m)

Table 7-5. SkyTEM data delivery to AGF

Folder Name:	Description of files
01_Data	SkyTEM provided data files 01_GDB (Geosoft database); 02_Workbench_SKB (Aarhus Workbench files); and 03_Workbench_XYZ (ASCII format)
02_Grids	SkyTEM provided Geosoft grids of the 01_EM, 02_DEM_Powerline, and 03_Mag
03_Maps	SkyTEM provided maps in Geosoft format and as *.pdf
04_Report	SkyTEM report to AGF as a *.pdf

Table 7-6. I-GIS Geoscene3D Project Files MRNRD_GeoScene_Project.zip

File Name:	Description of files
MRNRD.gsmod	MRNRD AEM GeoScene3D Project file
MRNRD_SCI04_forgeoscene.xyz	Inverted AEM data from the SCI inversions
MRNRD_DEM_SPM_v7_200.grd	Surfer 7.0 Digital elevation model for the MRNRD AEM survey area in NAD83 State Plane Nebraska meters with at 200 m grid cell size

8.0 References

- Asch, T.H., Abraham, J.D., and Irons, T., 2015, "A discussion on depth of investigation in geophysics and AEM inversion results", Presented at the Society of Exploration Geophysicists Annual Meeting, New Orleans.
- Christensen, N. B., J. E. Reid, and M. Halkjaer, 2009, "Fast, laterally smooth inversion of airborne time-domain electromagnetic data." *Near Surface Geophysics*, v.7, No. 5-6, p. 599-612.
- Christiansen, A. V., and E. Auken, 2012, "A global measure for depth of investigation." *Geophysics*, v.77, No. 4, WB171-177.
- Datamine Discover, 2020, Datamine Discover Profile Analyst, <https://www.dataminesoftware.com/solutions/discover-exploration-gis/>. (accessed on November 5, 2020)
- Foged, N, Auken, E., Christiansen, A.V., and Sorensen, K.I., 2013, Test-site calibration and validation of airborne and ground based TEM systems: *Geophysics*, v.78, No.2: E95-E106.
- HydroGeophysics Group, Aarhus University, 2010, "Validation of the SkyTEM system at the extended TEM test site." Aarhus, Denmark.
- HydroGeophysics Group, Aarhus University, 2011, "Guide for processing and inversion of SkyTEM data in Aarhus Workbench, Version 2.0."
- Korus, J. T. and Howard, L. M., 2019, Maps showing the physical hydrogeology and changes in saturated thickness (predevelopment to Spring 2016 and Spring 2011 to Spring 2016) in the Middle Republican Natural Resources District, Southwestern Nebraska: Conservation and Survey Division, no.664, <https://digitalcommons.unl.edu/conservationsurvey/664> (accessed November 5, 2020)
- Nebraska Department of Natural Resources, 2020, Registered Groundwater Wells Data Retrieval. <http://dnr.ne.gov/gwr/groundwaterwelldata> (accessed June 19, 2020)
- Schamper, C., Auken, E., and Sorensen, K., 2014, *Coil response inversion for very early time modelling of helicopter-borne time-domain electromagnetic data and mapping of near-surface Geologic Layers*. European Association of Geoscientists & Engineers, Geophysical Prospecting, v. 62, Issue 3, p. 658–674.
- University of Nebraska-Lincoln (UNL) School of Natural Resources, 2020a, Nebraska statewide test-hole database. <http://snr.unl.edu/data/geologysoils/NebraskaTestHole/NebraskaTestHoleIntro.aspx> (accessed June 23, 2020).
- University of Nebraska-Lincoln (UNL) School of Natural Resources, 2020b, Nebraska Geocloud. <http://snr.unl.edu/csd/geology/nebraskageocloud.aspx> (accessed November 5, 2020).
- U.S. Geological Survey (USGS), 2020, The National Map, 3DEP products and services: 3D Elevation Program Web page: <https://www.usgs.gov/core-science-systems/ngp/3dep/about-3dep-products-services> (accessed June 20, 2020)
- Viezzoli, A., A. V. Christiansen, E. Auken, and K. Sorensen, 2008, "Quasi-3D modeling of airborne TEM data by spatially constrained inversion." *Geophysics Vol. 73 No. 3* F105-F11.