SkyTEM Survey Drenthe - HydroGeophysics Group - Aarhus University

SkyTEM Survey Drenthe

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1. INTRODUCTION

In February 2017, a geophysical mapping with the airborne transient electromagnetic method SkyTEM was carried out in the Province of Drenthe, Netherlands. The mapping project was conducted in a cooperation between the HydroGeophysics Group, Department of Geoscience, Aarhus University, Denmark (HGG), the geological survey of the Netherlands (TNO) and Province Drenthe. The data collection was conducted by SkyTEM Surveys ApS, and a separate data report from SkyTEM Surveys documenting the data collection is available (SkyTEM Surveys: Data report Drenthe, Netherlands, May 2017).

This report primary presents the geophysical results (resistivity maps and cross sections) and documents the processing and inversion of the SkyTEM data. Chapters 2 - 4 describe the data collection, processing and inversion. Chapter 5 explain the various types of geophysical maps and cross section placed in Appendix I: - III.

This report does not address a geological interpretation of the obtained geophysical mapping results.

SkyTEM survey, Province Drenthe	
Client	Province Drenthe
Key persons	**HGG, Aarhus University, Denmark** Project management: *Professor, Esben Auken, M.Sc. Jesper B. Pedersen* Data processing and reporting: *Ph.D. Nikolaj Foged, Postdoc Denys Grombacher, M.Sc. Jesper B. Pedersen* **Province Drenthe** Rinke Van Veen Leo de Vree
Locality	Drenthe, the Netherlands
Survey period	The 10th of February – 22nd of February 2017
SkYTEM system	SkyTEM304
Line km acquired	2250 km
Line spacing	Overall: 100 m, in the southern part of the survey area 200 m

2. DATA COLLECTION

2.1 The Survey Area

The SkyTEM survey was carried out February 10th to February 22nd, 2017, with the SkyTEM 304 system, and covers a total of 2250 line km of data (Figure 1). The flight lines strike west-east with a line spacing of 100 m to 200 m (see Figure 1).

The average flight speed was approximately 18 m/s in a flight altitude of approximate 39 m (frame height). The flight altitude being strongly dependent on obstacles on the ground such as power lines, roads etc.

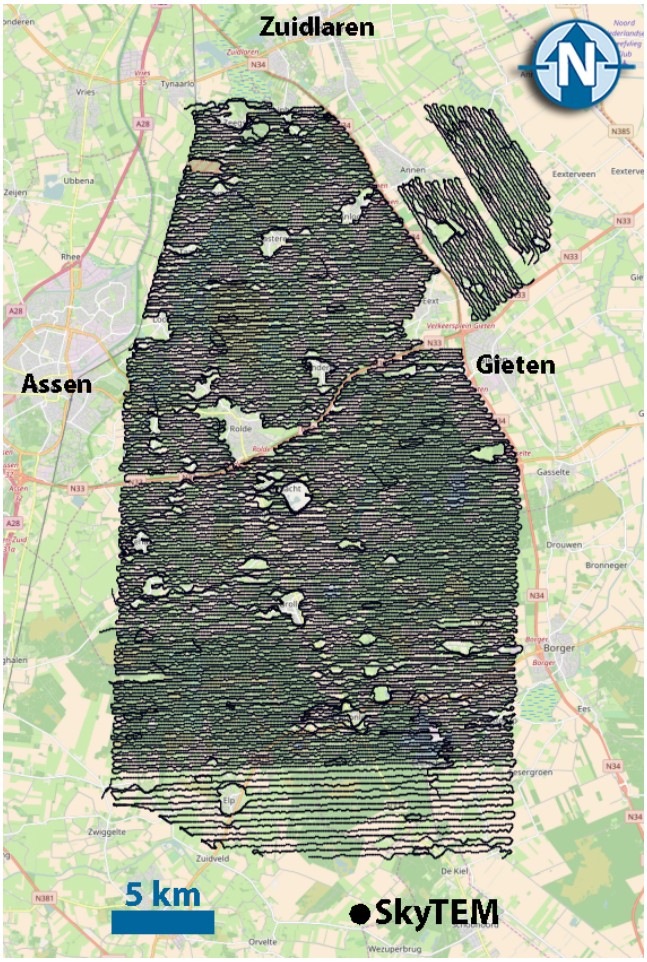

Figure 1. Survey area, with flight lines in black.

2.2 Overview of the SkyTEM System

SkyTEM is a time-domain helicopter electromagnetic system designed for hydrogeophysical, environmental, and mineral investigations. The following contains a general introduction to the SkyTEM system. A more thorough description of the SkyTEM method can be found in Sørensen et al., 2004. A description of the TEM method in general can be found in Nabighian and Macnae, 1991 and Jørgensen et al., 2003.

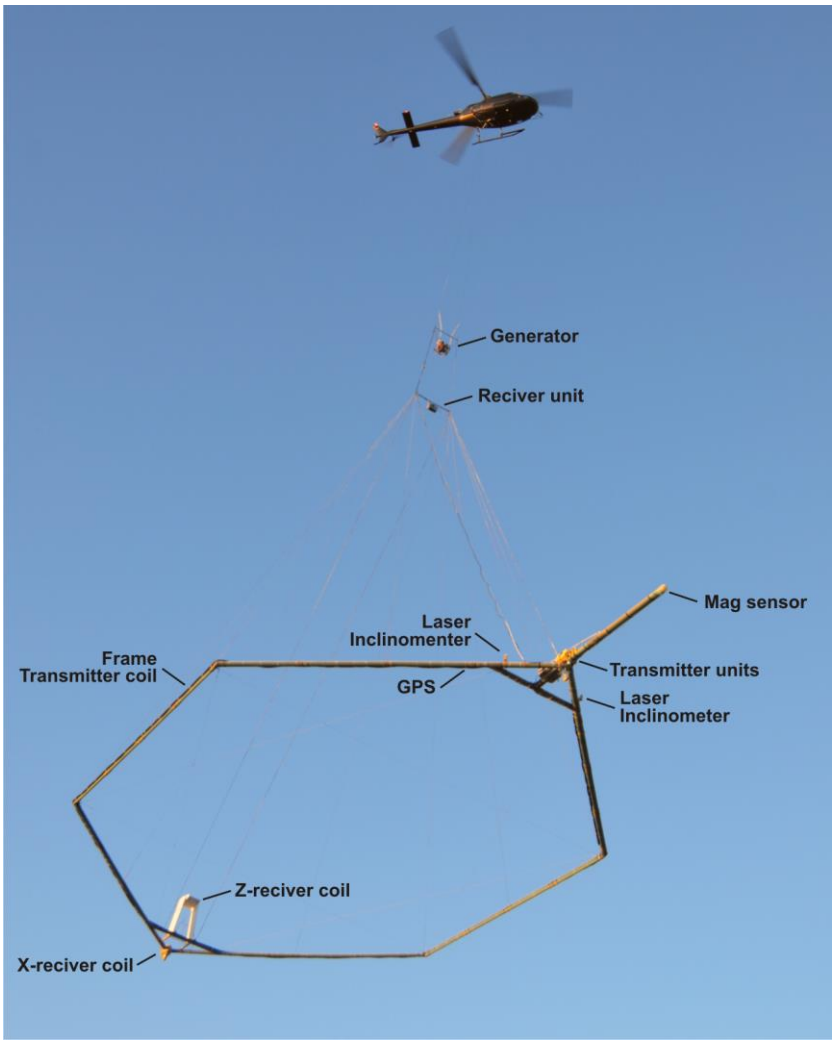

Figure 2. The SkyTEM304 system. The transmitter frame holds the inclinometers, laser-altimeters, receiver coils and instrumentation. For a detailed instrument setup see Figure 3.

Instrument

Figure 2 shows the SkyTEM system with the hexagonal frame below the helicopter. The lengths of the frame sides are approximately 11 m. The transmitter loop is mounted on the frame in an octagonal polygon configuration. The z-receiver coil is placed at the back, approximately 2 m above the frame, to obtain a close to zero coupling to the primary magnetic field. Two lasers are placed on the frame, continuously measuring the distance to the surface, and two inclinometers measure the roll and pitch of the frame. Power is supplied by a generator placed on the sling cable. The positions of the various devices on the frame are shown in Figure 3.

Measurement Procedure

The configuration of the system is customized for each survey. Measurements are carried out with one or two transmitter moments, depending on the target geology. The standard configuration uses a low and a high transmitter moment applied sequentially. A high and low moment sequence typically takes 2 seconds and includes several hundreds of individual transient measurements.

The flight altitude depends on the flight speed, on the roughness of the terrain, etc. A typical nominal flight altitude is 30-50 m (frame height). Over forested areas, the altitude is increased to maintain a safety clearing to the treetops. The flight speed can be adjusted to the survey area and target, up to a maximum speed of approximately 120 km/h.

Apart from GPS-, altitude- and TEM data, a number of instrument parameters are monitored and stored, in order to be used for quality control when the data are processed.

Penetration Depth

The penetration depth for the SkyTEM system depends on the transmitter moment, the geological settings, the background noise level, flight speed, and altitude. Normally, a penetration depth of 150-500 m can be achieved, but it strongly depends on primarily the SkYTEM system setup, the geological setting and the flight altitude. During the inversion a depth of investigation is estimated for each resistivity model (see section 4.4).

2.3 SkyTEM - Technical Specifications

This section holds detailed technical specifications of the SkyTEM304 system setup for this survey.

The SkyTEM system was configured in a standard two-moment setup (low moment, LM and high moment, HM).

The system instrument setup is shown in Figure 3. The positioning of the instruments and the corners of the octagon described by the transmitter coil are listed in Table 1. The origin is defined as the center of the transmitter coil.

The specifications of the LM an HM moment are summarized in Table 2.

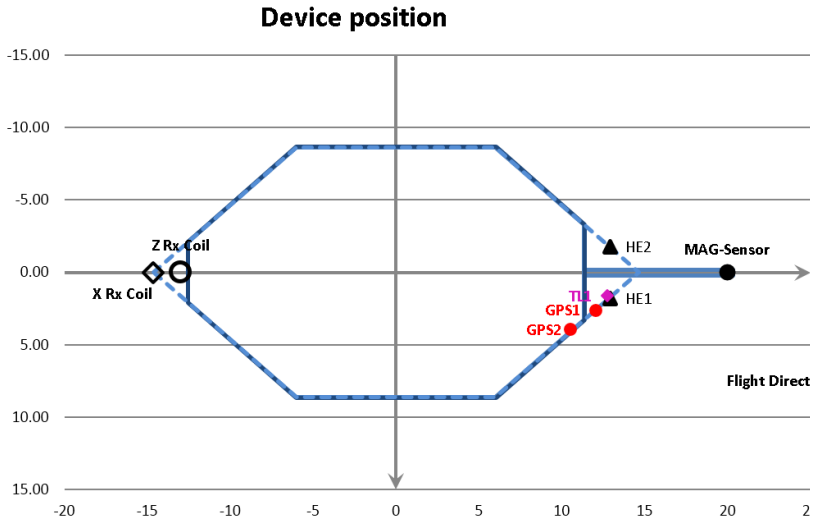

Figure 3. Instrument setup for the SkyTEM system used. HE 1 and 2 is laser altimeters, TL 1 inclinometer, GPS 1 and 2 are GPS sensors, X Z Rx Coil are the X and Z receiver coils.

Device Position

Unit	X (m)	Y (m)	Z(m)
DGPS1 (GPS)	11.68	2.79	-0.16
DGPS2 (GPS)	10.51	3.95	-0.16
HE1 (Altimeter)	12.94	1.79	-0.12
HE2 (Altimeter)	12.94	-1.79	-0.12
TL1 (inclinometer)	12.79	1.64	-0.12
TL2 (inclinometer)	12.79	1.64	-0.12
RxZ (Z-receiver coil)	-13.27	0.00	-2.0
RxX (X-receiver coil)	-14.65	0.00	0.00
Tx (center transmitter coil)	0.00	0.00	0.00
Mag sensor	20.50	0.00	-0.56
Loop corner 1	-12.64	-2.13	0.00
Loop corner 2	-6.15	-8.59	0.00
Loop corner 3	5.74	-8.59	0.00
Loop corner 4	11.13	-3.19	0.00
Loop corner 5	11.13	3.19	0.00
Loop corner 6	5.74	8.59	0.00
Loop corner 7	-6.15	8.59	0.00
Loop corner 8	-12.64	2.13	0.00

Table 1. Summary of equipment and transmitter coil corner positioning. The origin is defined as the center of the transmitter coil. Z is positive towards the ground.

Transmitter, Receiver Specifications

Parameter	LM	HM
No. of turns	2	4
Transmitter area	340.8 m^2	340.8 m^2
Tx Current	~ 9 A	~ 71 A
Tx Peak moment	~ 3000 Am^2	~ 10.000 Am^2
Repetition frequency	325 Hz	75 Hz
Tx-on-time	0.8 ms	2.5 ms
Tx-off-time	0.738 ms	4.167 ms
Duty cycle	52%	37%
Gate time interval	0.43 µs – 467.43 µs	0.43 µs – 3121.43 µs

Table 2. Summary of low moment (LM) and high moment (HM) specifications.

3. PROCESSING OF THE SKYTEM DATA

3.1 Pre-processing - Primary Field Compensation (PFC)

The magnetic field coupling between the receiver coils and the transmitter loops is hardware-monitored continuously, providing a separate value for the magnetic field coupling during each transient sounding. These data together with high altitude data (data records above ~400m altitude) from each flight are used to remove the primary filed part in raw data correction. The PFC enables accurate modeling of the very early time gates and modeling of on-time gates, by system response inversion in Aarhus Workbench.

PFC corrected data and the LM system response was derived by SkyTEM Surveys.

3.2 Data Processing – Workflow

The software package Aarhus Workbench is used for processing the SkyTEM data.

The aim of this processing is to prepare data for the geophysical interpretation. The processing primarily includes filtering and averaging of data as well as culling and discarding of distorted or noisy data.

The data processing can be divided into four steps:

1. Import of raw data into a fixed database structure. The raw data appear in the form of .skb-, .sps- and .geo-files. Skb-files contain the actual transient data from the receiver. Sps-files contain GPS positions, tilts, altitudes, transmitter currents etc. and the geo-file contains system geometry, low-pass filters, calibration parameters, turn-on and turn-off ramps, calibration parameters, etc. For a description of the SkyTEM file formats see Foged et al., 2011.
2. Automatic processing: First, an automatic processing of the four data types is used. These are GPS-, altitude-, tilt- and TEM data. This automatic processing is based on a number of criteria adjusted to the survey concerned.
3. Manual processing: Inspection and correction of the results of the automatic processing for the data types in question.
4. Adjustment of the data processing based on preliminary inversion results.

All data is recorded with a common time stamp. This time stamp is used to link data from different data types. The time stamp is given as the GMT time.

In the following, a short description of the processing of the different data types is shown. A more thorough description of the SkyTEM data processing can be found in Auken et al., 2009 .

3.3 GPS-Positioning

The position of the SkyTEM-system is recorded continuously with two independent GPS receivers. To obtain high precision, a local GPS based station was used to correct the recorded GPS (Differential GPS). The local GPS-base station data was provided by BRGM. Furthermore, the GPS data are shifted to the optimum forces point of the SkyTEM system, which are at approximate 2/3 of the distance from the center of the frame towards the receiver coil.

3.4 Roll and Pitch Data

The roll and pitch of the frame are measured and used to correct the altitude and voltage data. It is presumed that the frame is rigid so that the roll and pitch of the transmitter and receiver coils are identical.

3.5 Altitude Data

The distance between the transmitter coil and the ground is measured with two independent lasers. Figure 4 shows an altitude data example over open country with a minor forest area.

The aim of the altitude data processing is to remove reflections that do not come from the ground - typically reflections from treetops. The processing is based on the fact that reflections from tree tops etc. result in an apparently lower altitude than reflection from the surface. The automatic filtering of the altitude data is followed by a manual inspection and correction.

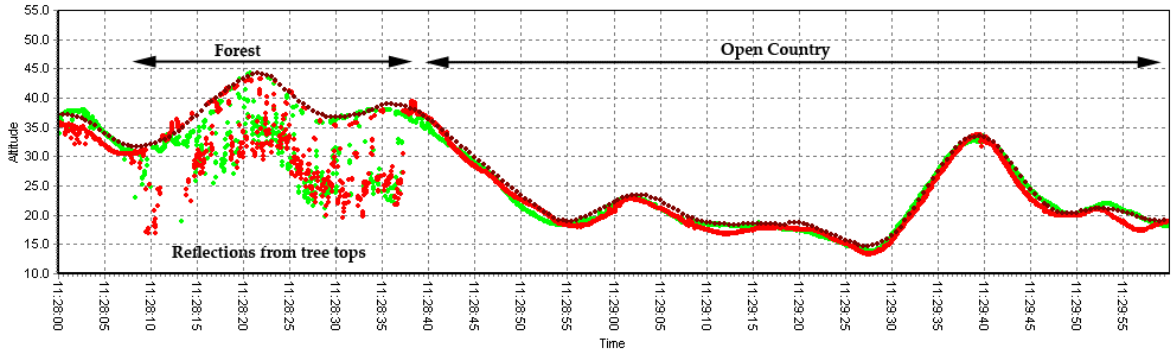

Figure 4. Green and red dots are raw data from the two laser altimeters. Brown dots are the resulting altitude after filtering the data. The time window holds approximate 2 km of data.

3.6 Voltage Data

The voltage data are gathered continuously along the flight lines and alternately with low and high moments. The processing of voltage data is carried out in a two-step system: an automatic and a manual part. In the former, data are corrected for the transmitter/receiver tilt, and a number of filters designed to cull coupled or noise influenced data are deployed.

To maximize the lateral resolution, no further stacking of the raw data is applied, resulting in a sounding for each 1.33 s (25-30 m depending on flight speed). Each sounding location will produce a resistivity model when data is inverted. The data uncertainty is calculated from the raw data stack, with an additional 3% uniform data uncertainty added.

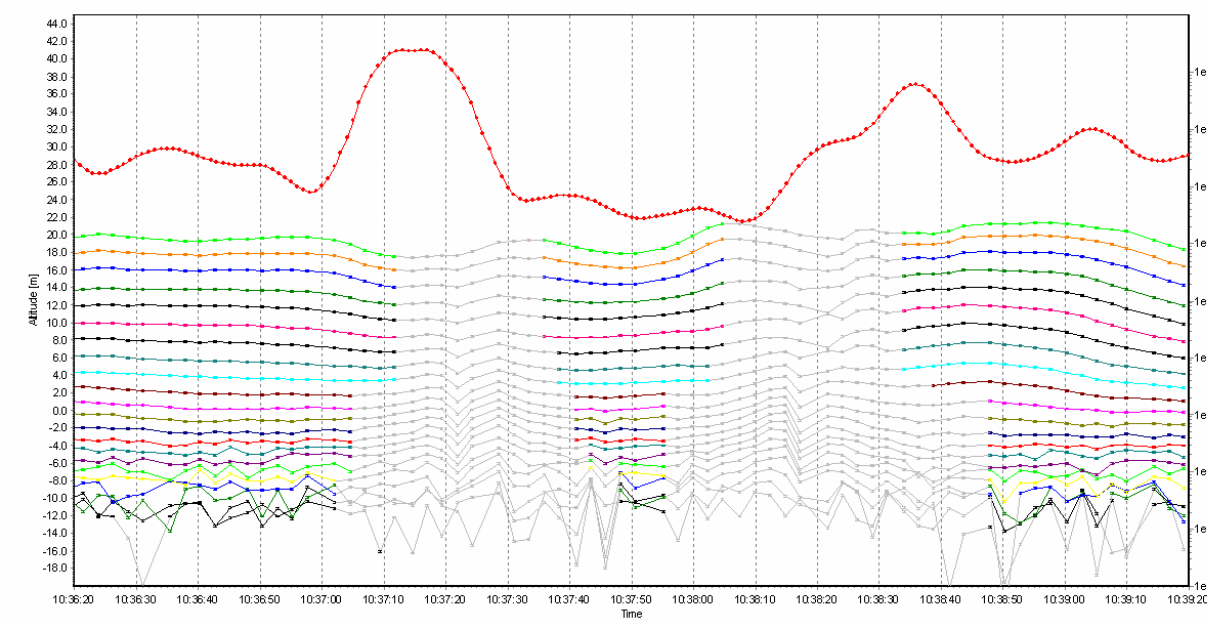

Figure 5. Data section example with coupled data. The section displays 3 minutes (~2.2 km) of data. The upper red curve shows the flight altitude. Each of the lower curves shows raw high-moment data for a given gate time. The green line represents gate 1 of the high moment, the orange line gate 2 etc. The grey lines represent data that have been removed due to couplings. Two couplings can clearly be identified at 10:37:20 and 10:38:20. Is this case the couplings are associated with installations along roads..

The automatic processing is always followed by a manual inspection and correction. Survey areas are typically crossed by a number of power lines, roads, railroads etc. As data near such installations often are heavily disturbed (couple to the installations), it is necessary to remove these data, in order to produce geophysical maps without artifact from these manmade installations. The manual inspection and removal of coupled data is therefore essential to obtain high quality end results. In some cases it is not possible to identify the source of the coupling even though it is evident in the data.

Figure 5 shows an example of strongly coupled data. First the coupled data parts are removed. Then data are stacked into soundings, and finally the late-time part of the sounding curves below the background noise level is excluded.

3.7 Processing - Technical Specifications

Table 3 shows key processing settings in the Aarhus Workbench, used for this survey.

Item		Value
Software	Aarhus Workbench Version	5.2.2
Noise Processing	Data uncertainty: Uniform data STD	From data stack 3%
Stacking	Sounding distance	0.6 s (10.8 m lateral spacing at flight speed of 18 m/s)

Table 3. Processing settings.

4. INVERSION OF THE SKYTEM DATA

Inversion of the dataset and evaluation of the inversion results are carried out using the Aarhus Workbench software package. The underlying inversion code (AarhusInv) is developed by the HydroGeophysics Group, Aarhus University, Denmark (Auken et al., 2015).

The inversion is a 1D full non-linear damped least-squares solution in which the transfer function of the instrumentation is modeled. The transfer function includes turn-on and turn-off ramps, front gate, low-pass filters, and transmitter and receiver positions. The flight altitude contributes to the inversion scheme as a model parameter with the laser altimeter readings as a constrained prior value.

4.1 System Reponse Modeling

With the system response modeling scheme (Andersen et al., 2017) the waveform, low-pass filters etc. are not modeled separately, but as a system response measured for the specific SkyTEM setup. This approach enables accurate modeling of gates in the ramp down time, providing a better near surface resolution in the resulting resistivity models.

For this survey, two extra gates located during ramp down are included in the inversion (**Error! Reference source not found.**).

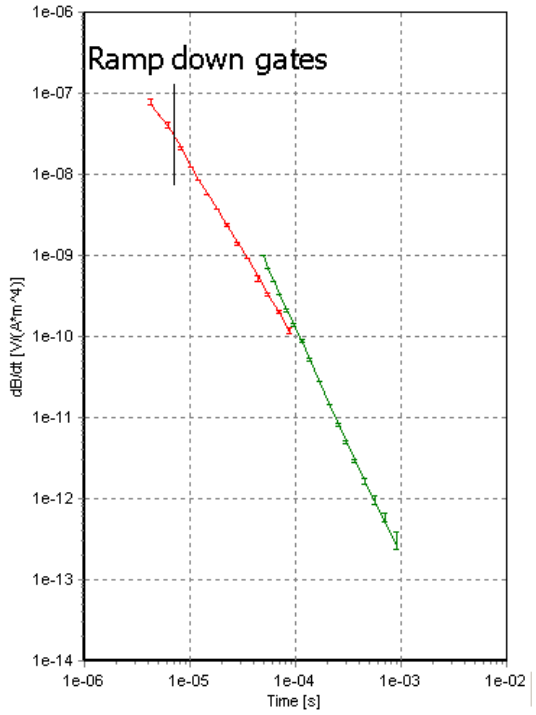

Figure 6. HM (green) and LM (red) dB/dt sounding curves. The gate left to the black line are located in the ramp down time.

4.2 Spatially Constrained Inversion

The spatially constrained inversion (SCI) scheme is used when inverting the SkyTEM data. The SCI scheme uses constraints between the 1D-models, both along and across the flight lines, as shown in Figure 6. The constraints are scaled according to the distance between soundings.

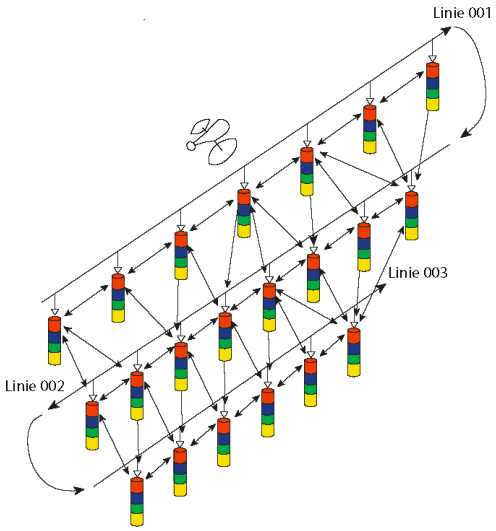

Figure 6. Schematic presentation of the SCI setup. Constraints connect not only soundings located along the flight line, but also those across them.

The connections pattern of the constraints is designed using a Delaunay triangulation, which connects *natural* neighbor models. For line oriented data the Delaunay triangulation results in a model being connected to the two neighbor models at the flight line and typically 2-3 models at the adjacent flight lines, (see Figure 7). The SCI constraints are the preliminary condition for breaking down the line orientation in the dataset.

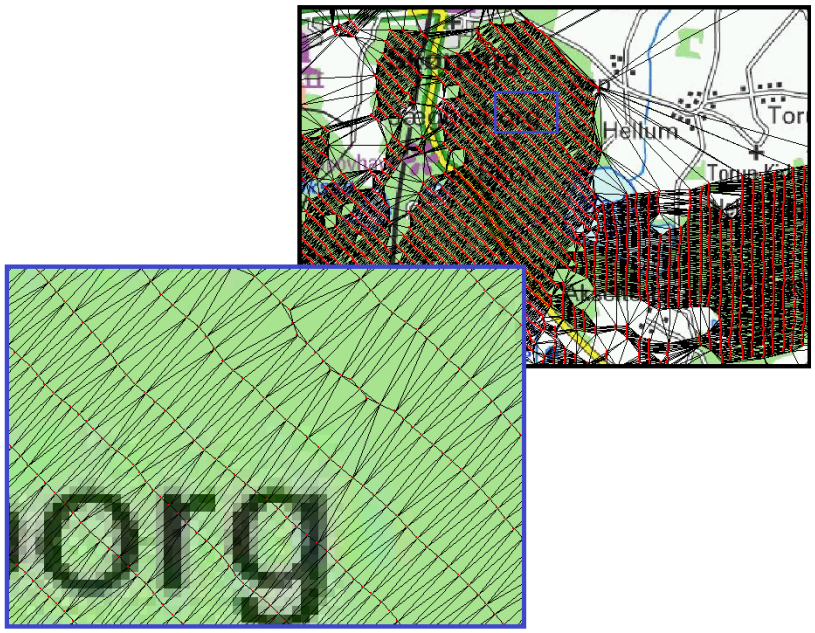

Figure 7. Example setup of SCI-constraints. The red points are the model positions. The black lines show the constraints created with the Delaunay triangles. The line distance in this example is 160 m and the zoomed area is approximately 1.2 x 0.85 km.

Constraining the parameters enhances the resolution of resistivities and layer interfaces, which are not well resolved in an independent inversion of the soundings.

SCI-setup parameters for this survey are listed in section 4.5.

4.3 Smooth, Sharp Inversion

Both a smooth and a sharp model inversion have been carried out. Both inversion types use the SCI-setup, but the regularization scheme is different.

The smooth regularization scheme penalizes the resistivity changes, resulting in smooth resistivity transitions both vertical and horizontal, as seen in Figure 7. The sharp regularization scheme penalizes the number of resistivity changes of a certain size, resulting in model sections with few, but relative shape resistivity transitions, as seen in see Figure 7. Normally the SkyTEM are data explained equally well with the model types.

Assuming a geological layered environment, picking geological layer boundaries, will be less subjective in a sharp model result compared to a smooth model.

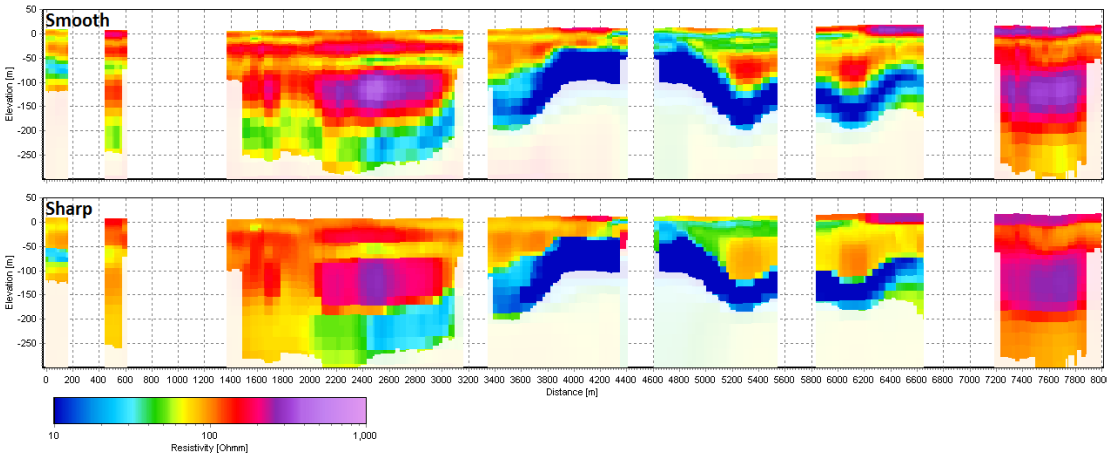

Figure 8. Profile examples of a sharp and smooth inversion of the same SkyTEM data set. The black line shows the data residual, which is equally good for the two model types in this case.

4.4 Depth of Investigation

For each resistivity model a depth of investigation (DOI) is estimated, as described in Christiansen and Auken, 2012. The DOI calculation takes into account: the SkyTEM system transfer function, the number of data points, the data uncertainty, and the resistivity model.

EM fields are diffusive, and there is no discrete depth where the information on the resistivity structure stops. Therefore, we provide an conservative and a standard DOI estimate. As a guideline, the resistivity structures above the DOI conservative value are well consolidated by the SkyTEM data, and resistivity structures below the DOI standard value are very weakly founded in the data and should normally be disregarded.

The DOI conservative and DOI standard estimates are included as point themes map in Appendix I: The cross sections in Appendix II: are blanked in depth at the DOI standard values. Furthermore, the resistivity models are blanked below the DOI- standard value when compiling the mean resistivity maps.

4.5 Inversion - Technical Specifications

The inversion settings for the sharp and smooth inversions in Aarhus Workbench are listed Table 4.

Item		Value
Software	Aarhus Workbench Version	5.3.1
Model setup	Number of layers Starting resistivities [Ωm] Thickness of first layer [m] Depth to last layer [m] Thickness distribution of layers	30 Auto 2.0 300.0 Log increasing with depth
Smooth model: Constraints/ Prior constraints	Horizontal constraints on resistivities [factor] Reference distance [m] Constraints distance scaling Vertical constraints on resistivities [factor] Prior, thickness Prior, resistivities Prior on flight altitude [m] Lateral constraints on flight altitude [factor] Minimum number of gates per moment	1.3 15 (1/distance)[1] 3.0 Fixed None +/- 2 1.3 7
Sharp model: Constraints/ Prior constraints	Horizontal constraints on resistivities [factor] Horizontal sharp Reference distance [m] Constraints distance scaling Vertical constraints on resistivities [factor] Vertical sharp Prior, thickness Prior, resistivities Prior on flight altitude [m] Lateral constraints on flight altitude [factor] Minimum number of gates per moment	1.05 200 15 (1/distance)[1] 1.10 100 Fixed None +/- 2 1.3 7

Table 4. Inversion settings, smooth/sharp SCI setup

5. THEMATIC MAPS AND CROSS SECTIONS

To visualize the resistivity structures in the mapping area, a number of geophysical maps and cross sections have been created. Furthermore, a location map and a number of maps made for quality control (QC-maps) are found in the appendices.

5.1 Mean Resistivity Maps

To make depth or horizontal slices, the mean resistivity in the depth or elevation intervals is calculated for each resistivity model and then interpolated to a regular grids.

Figure 9 shows how the resistivities of the layers in a model influence the calculation of the mean resistivity in a depth interval [A, B]. d_0 is the surface, d_1, d_2 and d_3 are the depths to the layer boundaries in the model. ρ_1, ρ_2, ρ_3 and ρ_4 are the resistivities of the layers.

The model is subdivided into sub-thicknesses $\Delta t_{1\text{-}3}$. The mean resistivity ($\rho_{vertical}$) is calculated as:

$$\rho_{vertical} = \frac{\rho_1 \cdot \Delta t_1 + \rho_2 \cdot \Delta t_2 + \rho_3 \cdot \Delta t_3}{\Delta t_1 + \Delta t_2 \cdot \Delta t_3}$$

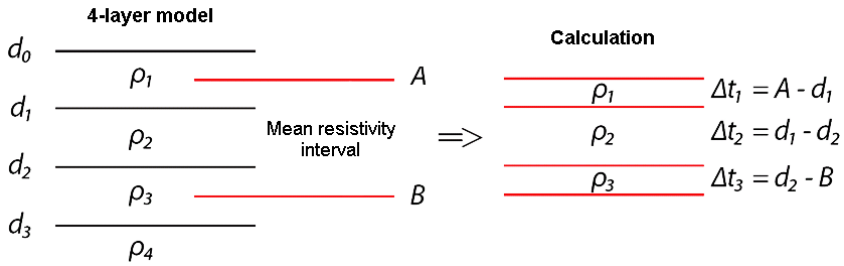

Figure 9. The figure illustrates how the resistivities of the layers influence the mean resistivities in a depth interval [A:B]

In the general term the mean resistivities in a depth interval is calculated using the equation below:

$$\bar{\rho} = \frac{\sum_{i=1}^{n} \rho_i \cdot \Delta t_i}{\sum_{i=1}^{n} \Delta t_i}$$

where i runs through the interval from 1 to the number of sub-thicknesses. The mean resistivity calculated by the above formula ($\rho_{vertical}$) is named the vertical mean resistivity - equal to the total resistance if a current flows vertically through the interval.

By mapping with a TEM method, the current flows only horizontally in the ground. It is therefore more correct to perform the mean resistivity calculation in conductivity in the space, then named the horizontal mean resistivity ($\rho_{horizontal}$). The horizontal mean resistivity is equal to the reciprocal of the mean conductivity (σ_{mean}) and is calculated as:

$$\rho_{horizontal} = \frac{1}{\sigma_{mean}} = \left[\frac{\sum_{1=1}^{n}\left(\frac{1}{\rho_i}\right) \cdot \Delta t_i}{\sum_{i=1}^{n} \Delta t_i}\right]^{-1}$$

For this survey, horizontal mean resistivity themes have been generated from the smooth model inversion result in 5 m depth intervals from 0 to 50 m, and in 210 m intervals from 50 to 3000 m. The resistivity models have been blanked at the DOI standard value prior to the interpolation regular mean resistivity grids.

The interpolation of the mean resistivity values to regular grids is performed by Kriging interpolation (Pebesma and Wesseling, 1998), with a node spacing of 25 m and a search radius of 400 m, and with additional pixel smoothing in the presented bitmaps images. The mean resistivity maps are placed in Appendix III:

5.2 Cross Sections

Cross sections of selected flight lines are included in Appendix II: Each section holds the model bars, which are blanked at the DOI-standard value. Cross section of all flight lines are available in the deliveredWorkspace.

5.3 Location Map, QC-maps

A location map and quality control maps (QC) described below are included in Appendix I:

Model Location and Flight Lines
This map shows the actual flight lines. Black dots mark where data are disregarded due to line turns or coupling. Blue dots mark where data is kept and inverted to a resistivity model.

A decent amount of data is disregarded due to coupling, and the coupled data are primarily associated with electrical cables, roads and the railway.

Moment Indication
This map shows if both low and high moment data are present. In general, both moments are present for the whole survey. In some cases a coupling is only observed in one of the moments, resulting in only data from the other moment being present.

Number of Time Gates in use
This maps shows the number of time gates (high and low moment) in use for each resistivity model. Few time gates correlate to areas with a low signal level (very resistive areas) and/or a relative high flight altitude.

Flight Altitude
This map shows the processed flight altitudes from the laser altimeters (distance from the frame to the ground).

The flight altitude reflects the necessary safety distance to the ground, treetops, etc. The altitude span between ~25 and ~65 m.

Data Residual
The data residual tells how well the obtained resistivity models explain the recorded data (how well the data is fitted). The data residual values are normalized with the data standard deviation, so a data residual below one corresponds to a fit within one standard deviation.

The data residual map in Appendix I: is for the smooth inversion result. The data residuals for the sharp inversion is similar. Some areas have relatively high data residual values (>2), this is primarily due to noise data, which again is associated to low signal ground responses (resistive ground) and/or a high flight altitude. In general, the data residuals are really good, which is expected for this type of environment and geological setting.

Depth of Investigation (DOI)
This map shows the DOI estimates for the smooth model inversion result (see section 4.4 for a description of the DOI-calculation). DOI maps in elevation and depths are included in the appendix.

5.4 Deliverables

Digital

- This report incl. theme maps and profiles as PDF-files.

- Aarhus Workbench workspace holding raw data, processed data, inversion results, theme maps and profiles. Figure 10 gives an overview of the tree structure in the workspace. The workspace holds both the smooth and the sharp inversion results.
  The workspace can be delivered upon request.

- Mean resistivity maps in depth intervals as GeoTIFF files.
  …\MRESD_##_##.tif

- QC-maps in ArcGIS shape format.
  *…\QC_maps***.shp*

- Resistivity models in xyz-ascii files, for both the sharp and smooth model.
  …\xyz_ascii\Sharp_model.xyz, Smooth_model.xyz.

Note: All digital maps and data are geo-referenced to coordinate system WGS84, UTM zone 32N.

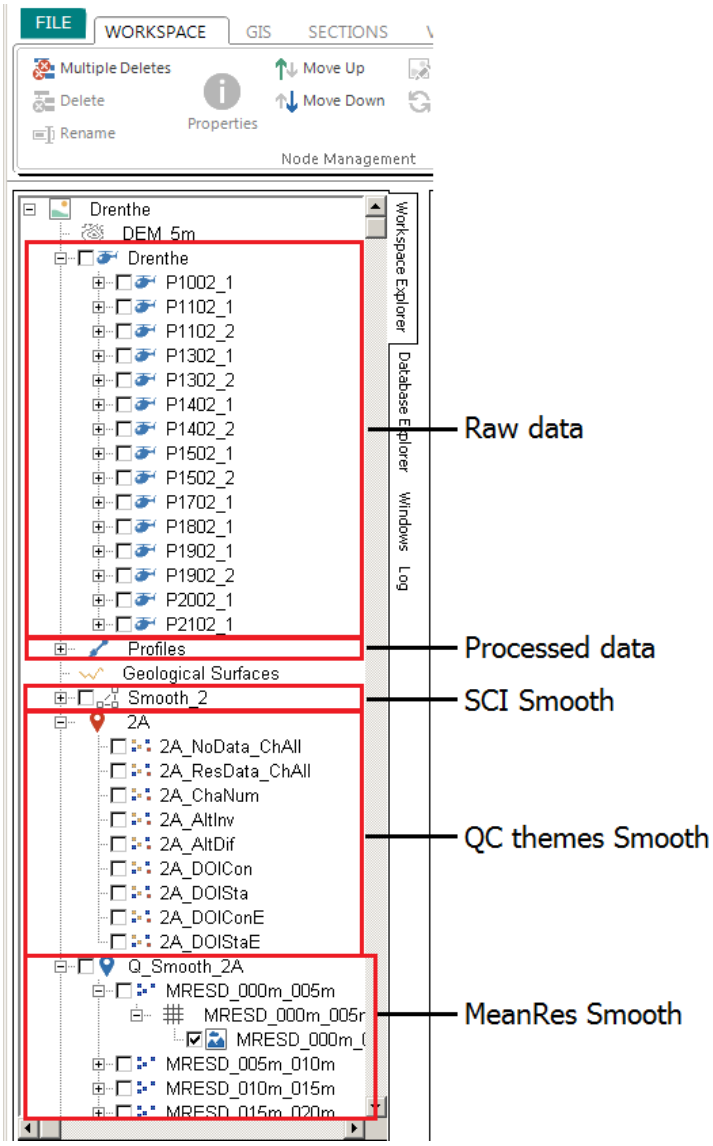

Figure 10. Tree structure in the Drenthe workspace.

6. CONCLUSION

The SkyTEM survey was carried out successfully despite rough winds and foggy weather.

A careful data processing has been carried out and the new system response modeling approach has successfully been used in the inversion of the data, enabling modeling of time gates in the ramp down time. Both a smooth and a sharp resistivity model result has been generated.

The SkyTEM survey reveals a detailed three-dimensional resistivity picture of the subsurface.

Further geological interpretation of the 3D-resistivity results is needed to make full use the SkyTEM survey results. This work includes adding regional information to make the model more detailed. This worked will be carried out by TNO, Holland, who are experts in the geological setting of the area, and know how to incorporate a-priori knowledge such as boreholes and electrical conductivity logs into the interpretation of the SkyTEM dataset. However, this work is not reported in this report, as it is the next step of the project. TNO will report the findings of this additional work in a separate report.

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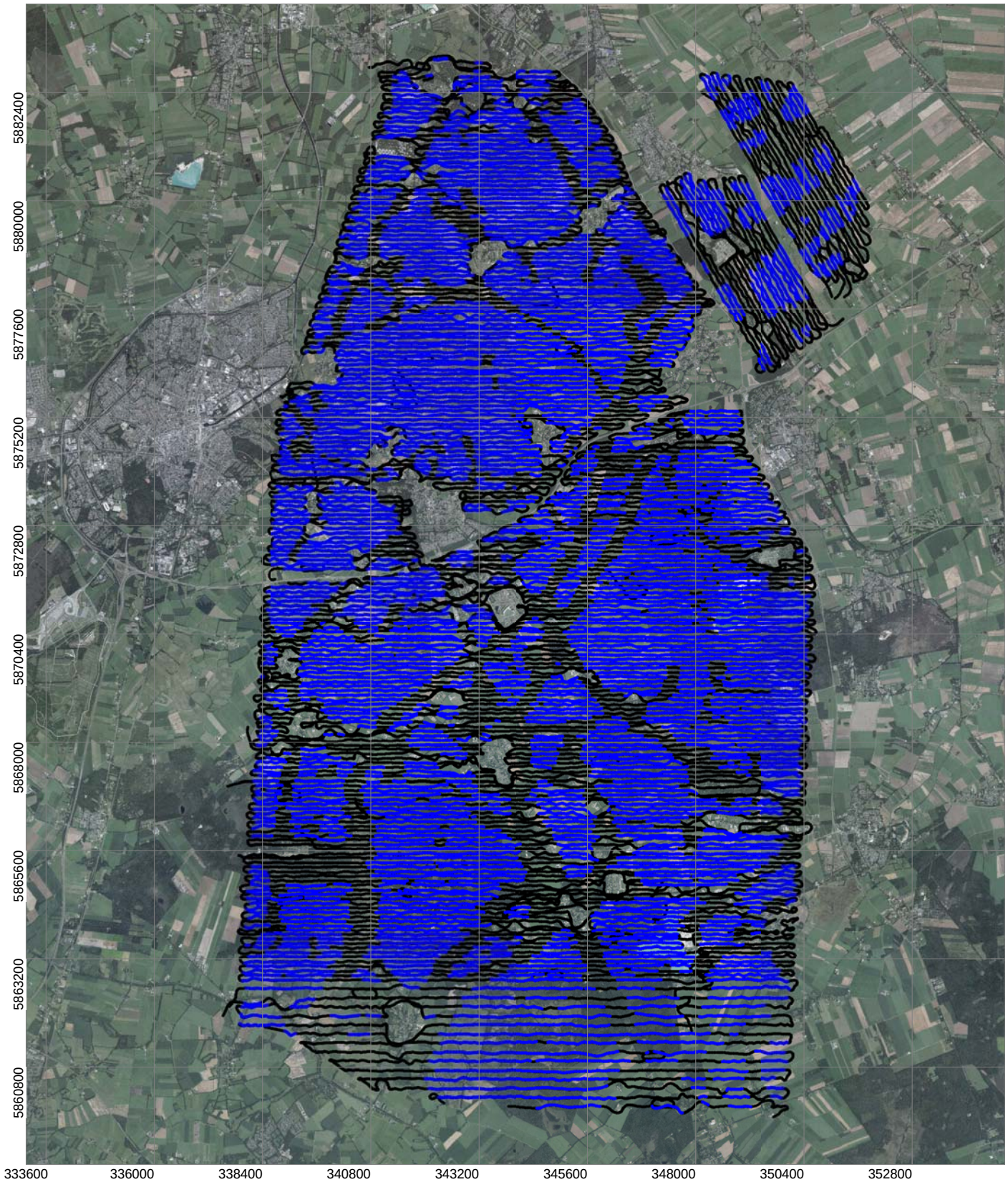
APPENDIX I: LOCATION MAPS, QC MAPS

This appendix includes maps of:

- Model location and flight lines
- Model moment indication
- Flight altitude
- Data residual
- Number of datapoints
- Depth of investigation, in elevation and depth



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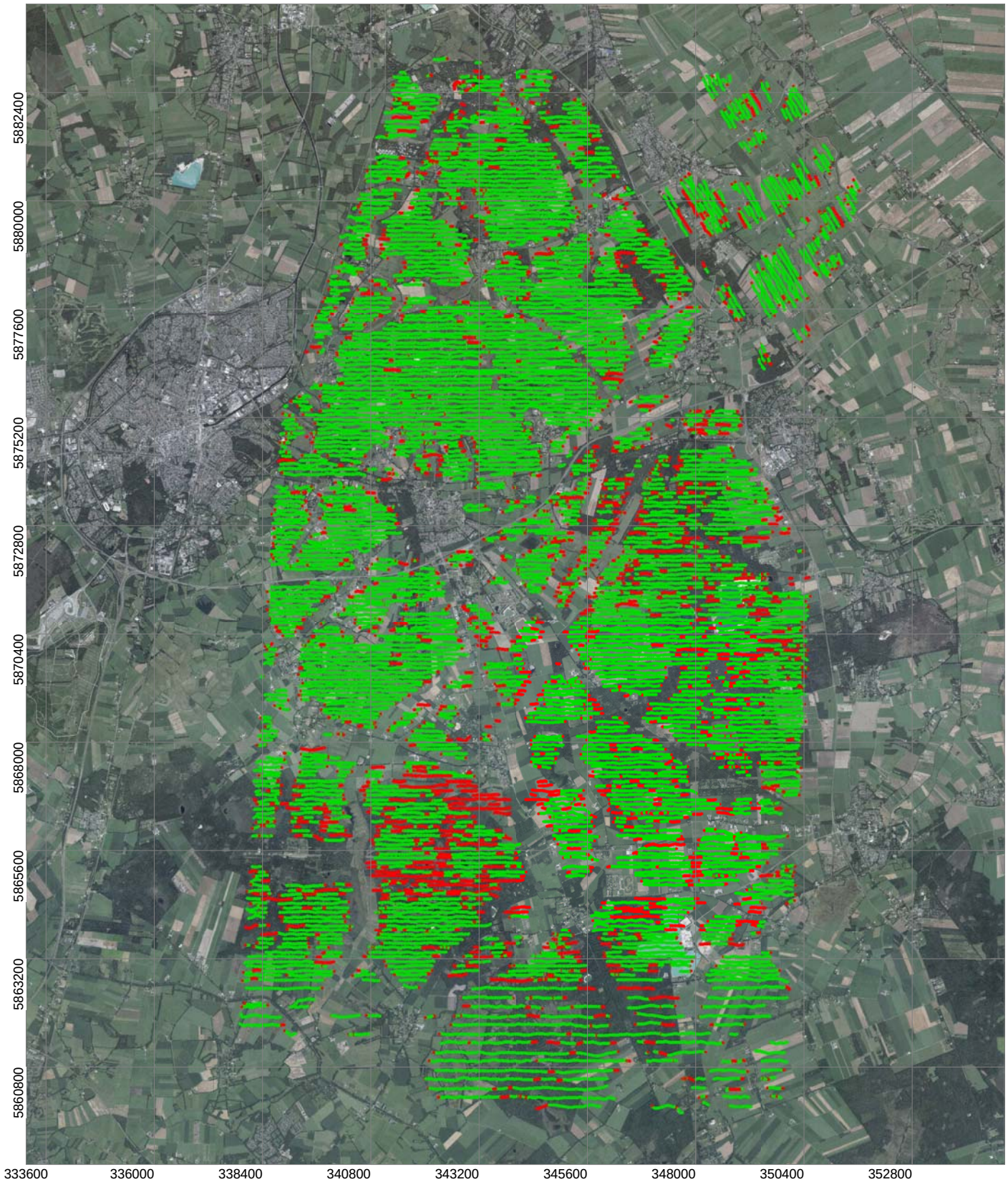
Location, flight lines

Blue: 1D model Black: Discarded data

UTM 32N WGS84

5 km



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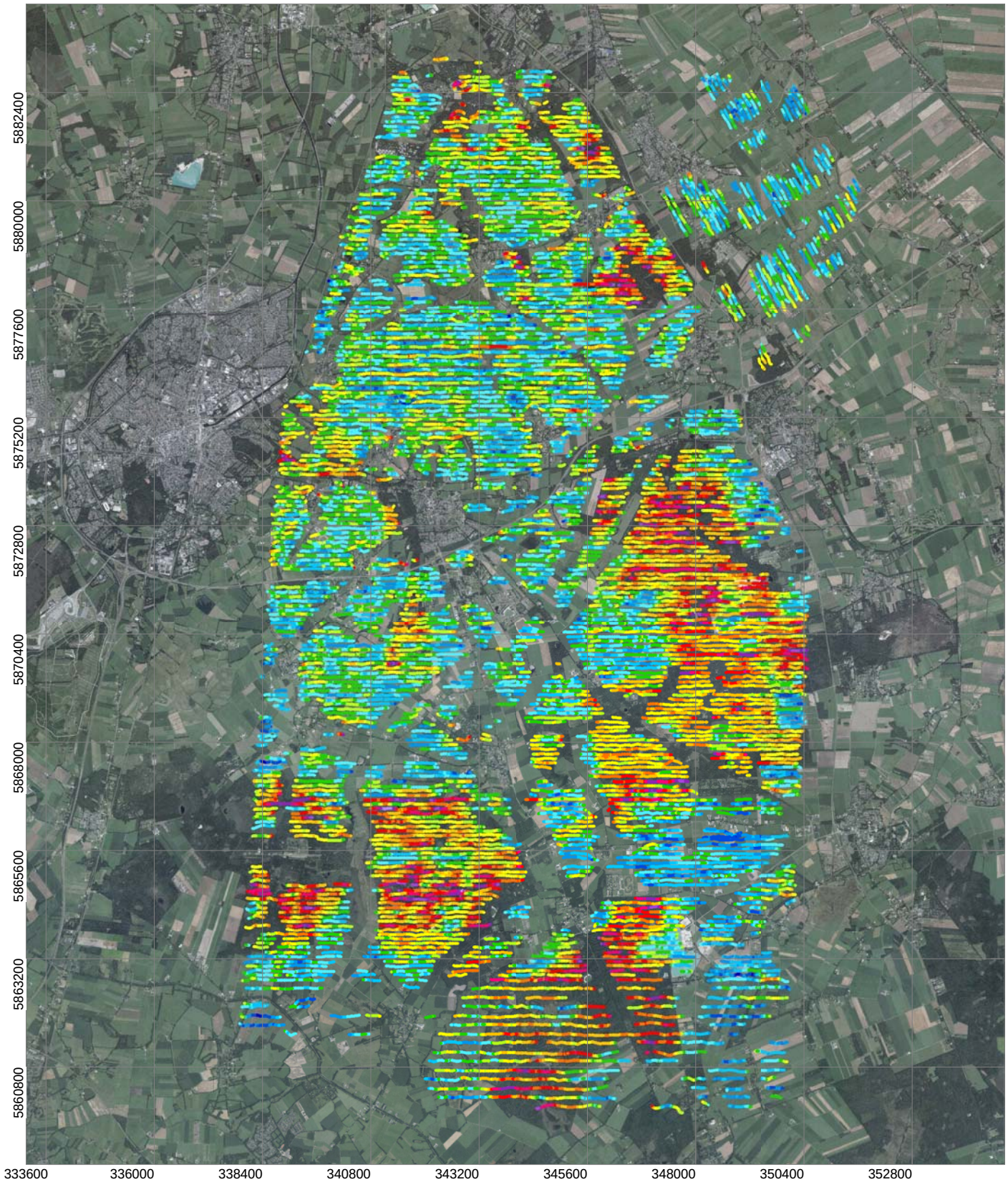
Model Moment Indications

Green: LM and HM - Red: LM only - Blue: HM only

UTM 32N WGS84

5 km



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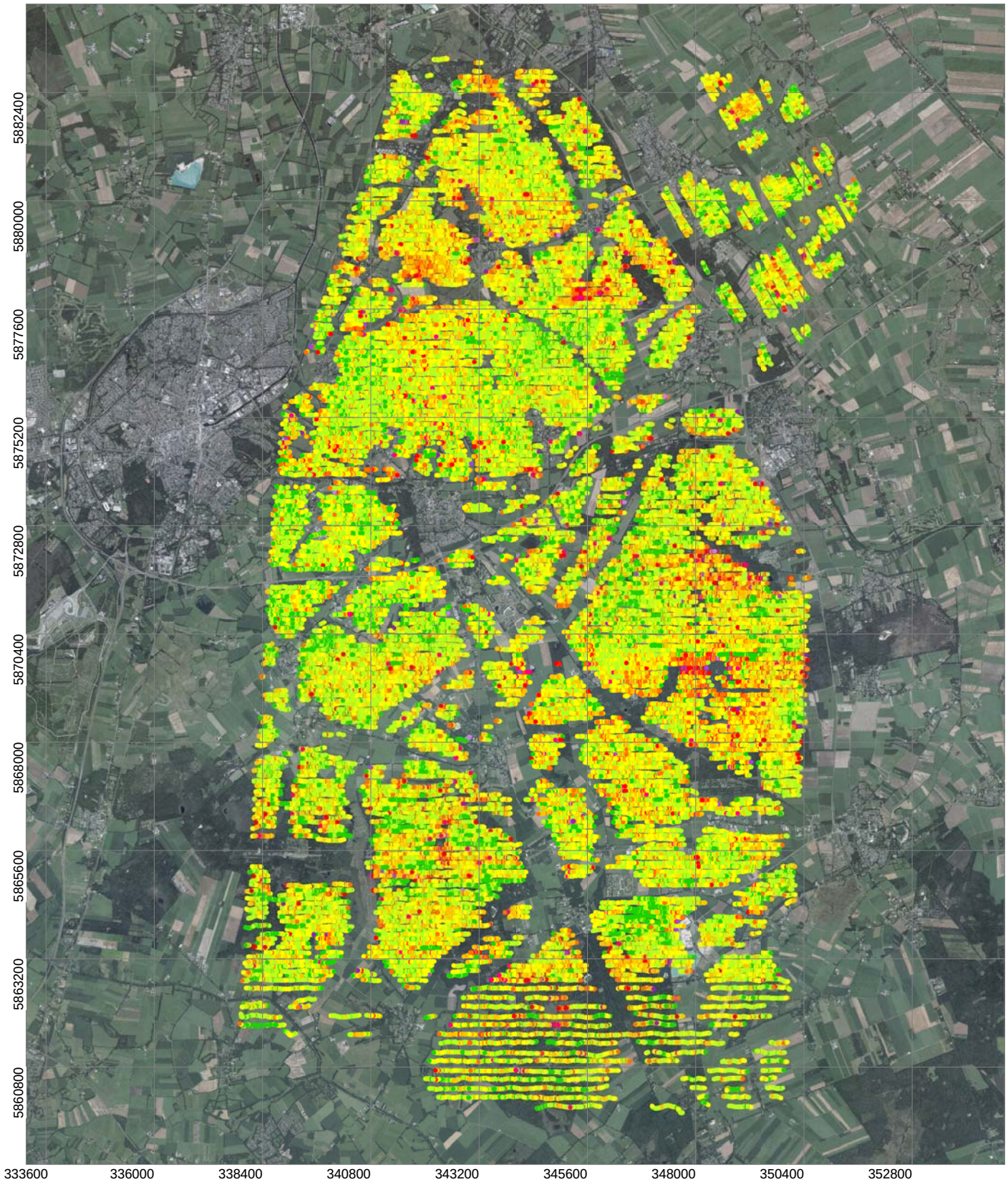
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Altitude [m]

Flight Altitude
Elevation, meters

UTM 32N WGS84

5 km



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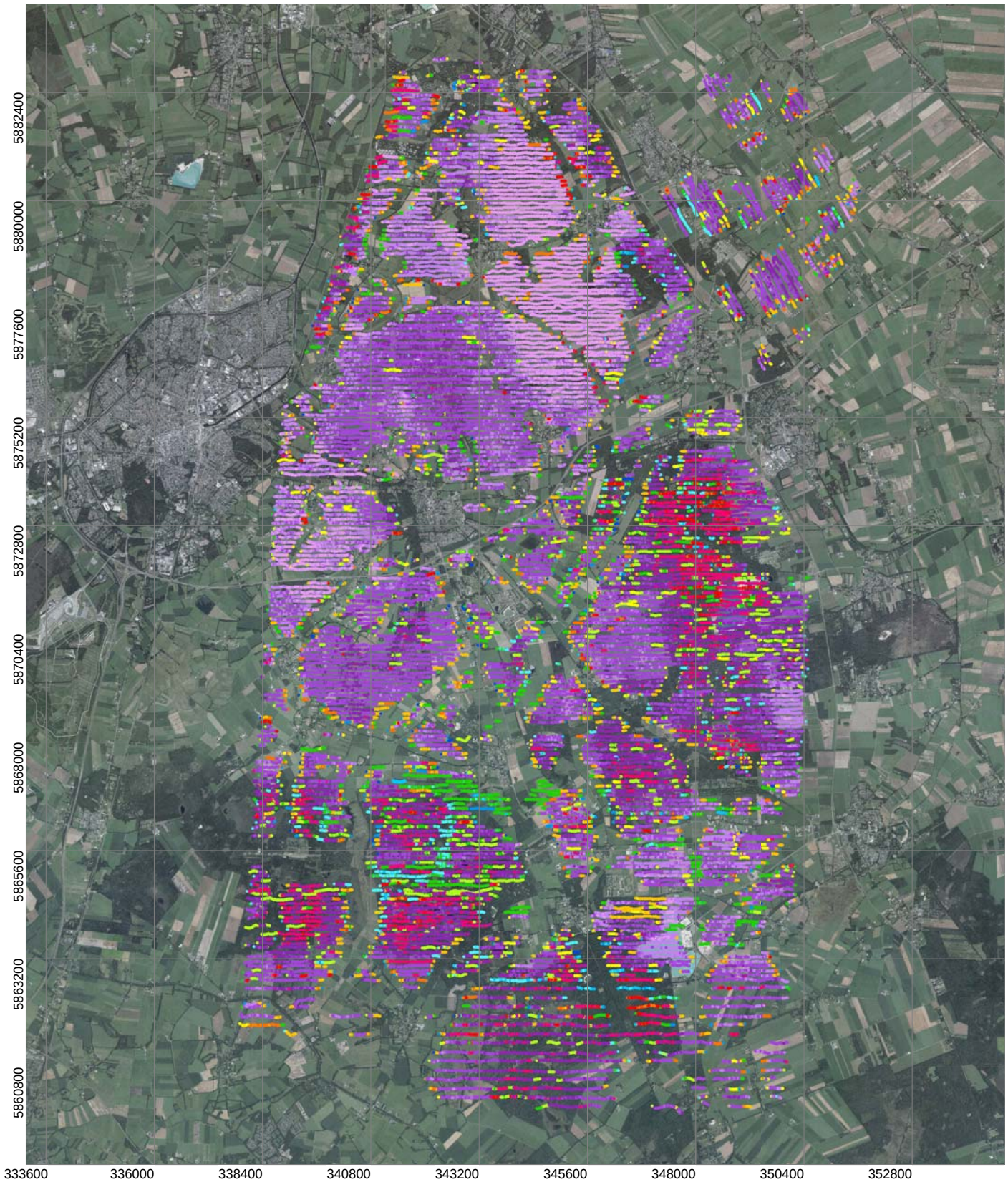
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2 3.4

Data Residual

Below one corresponds to a fit within one standard deviation

UTM 32N WGS84

5 km



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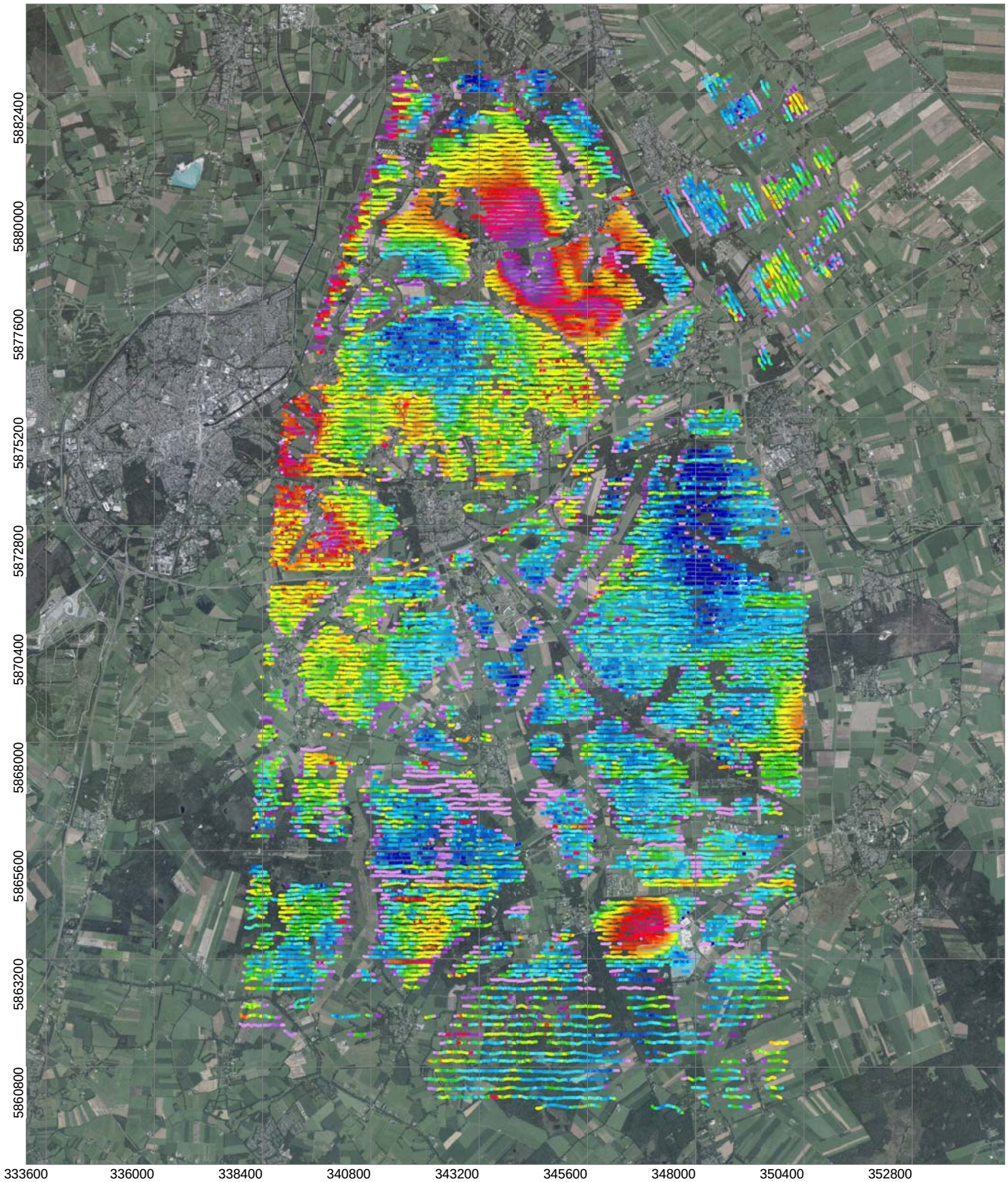
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36

Number of Datapoints

Time gates used for inversion

UTM 32N WGS84

5 km



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SkyTEM Survey Drenthe 2017

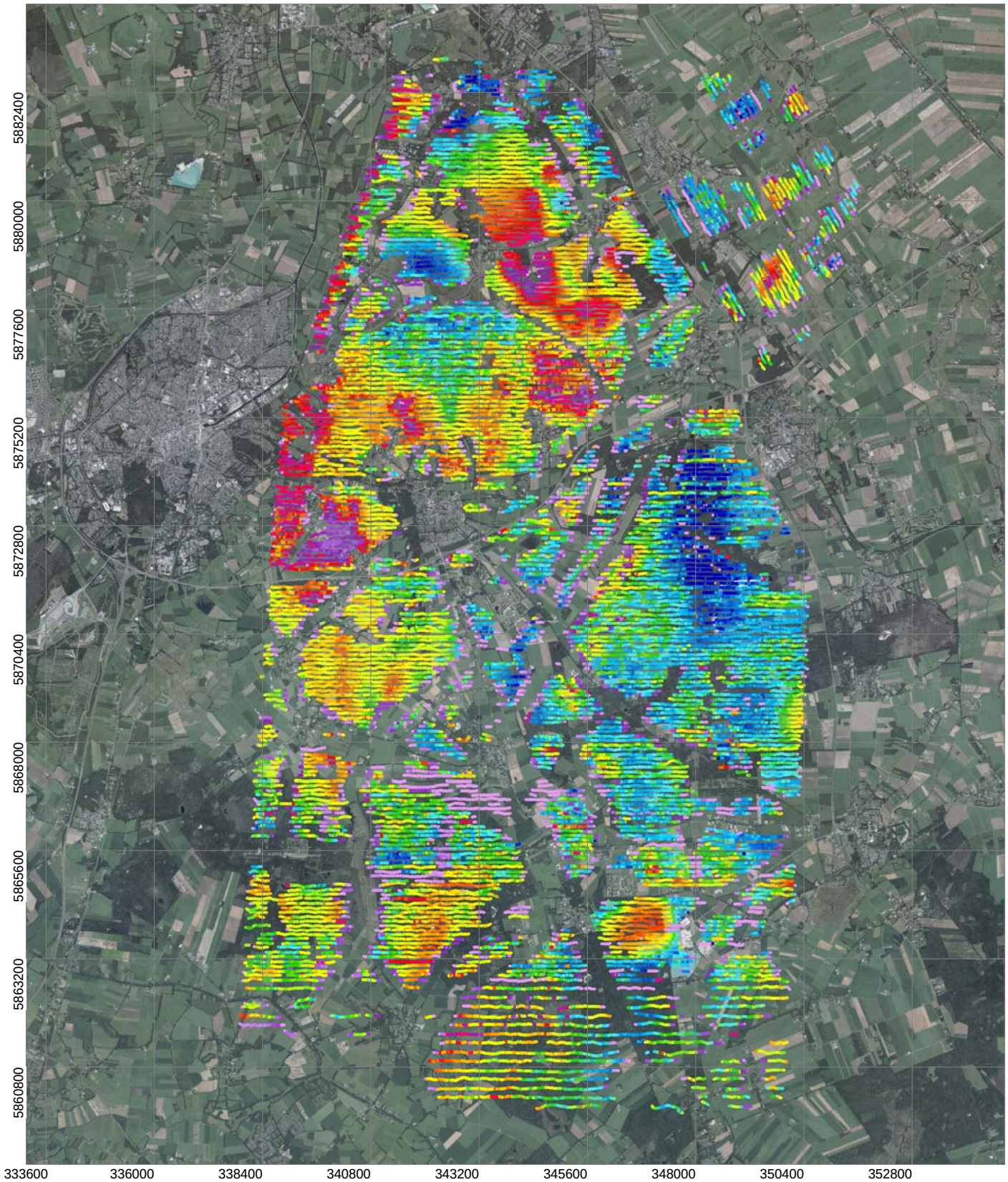
-300 -250 -200 -150 -100 -50 0
Elevation [m]

Depth of Investigation, Standard

Elevation, Meters

UTM 32N WGS84

5 km



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SkyTEM Survey Drenthe 2017

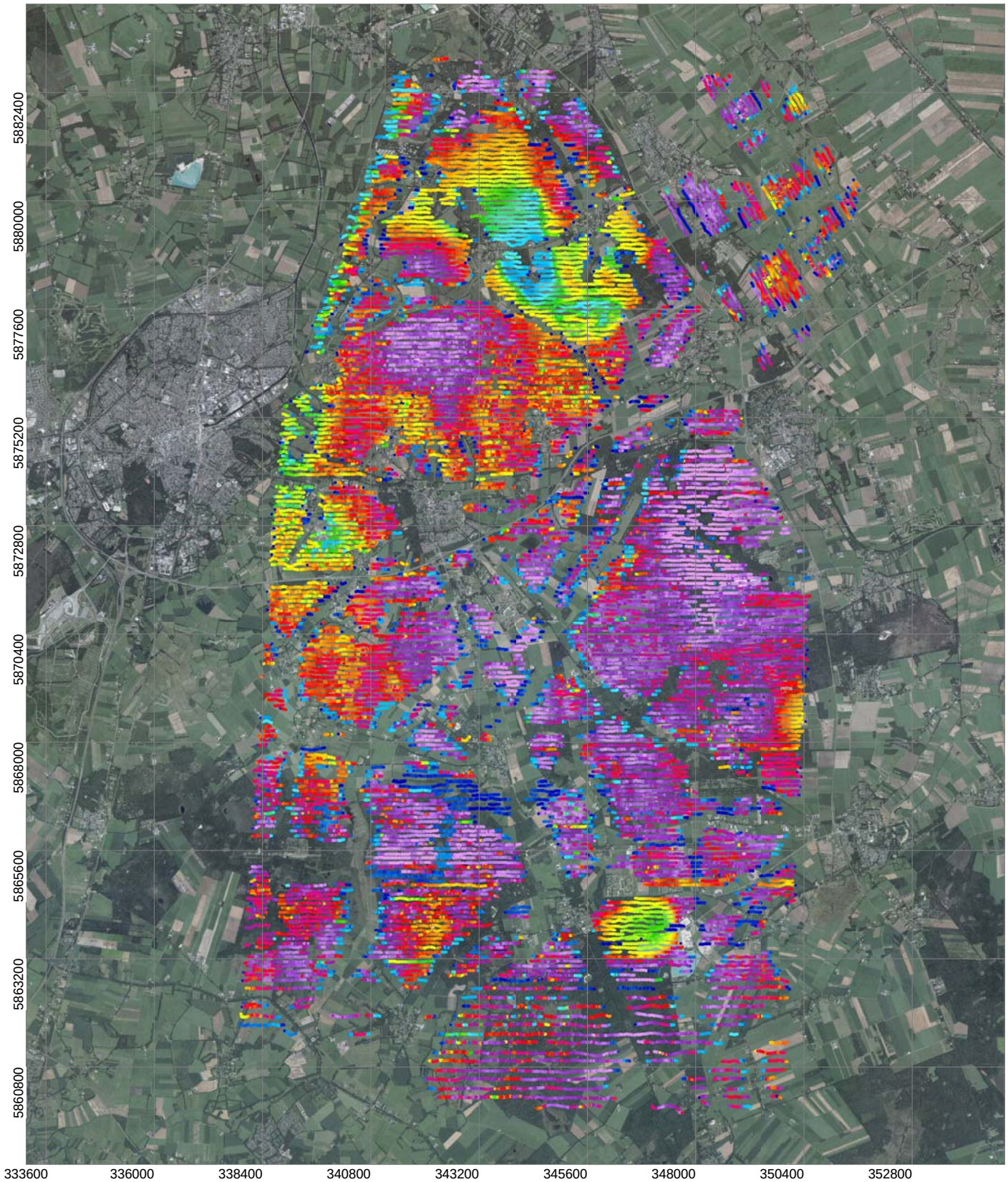
-250 -200 -150 -100 -50 0
Elevation [m]

Depth of Investigation, Conservative

Elevation, Meters

UTM 32N WGS84

5 km



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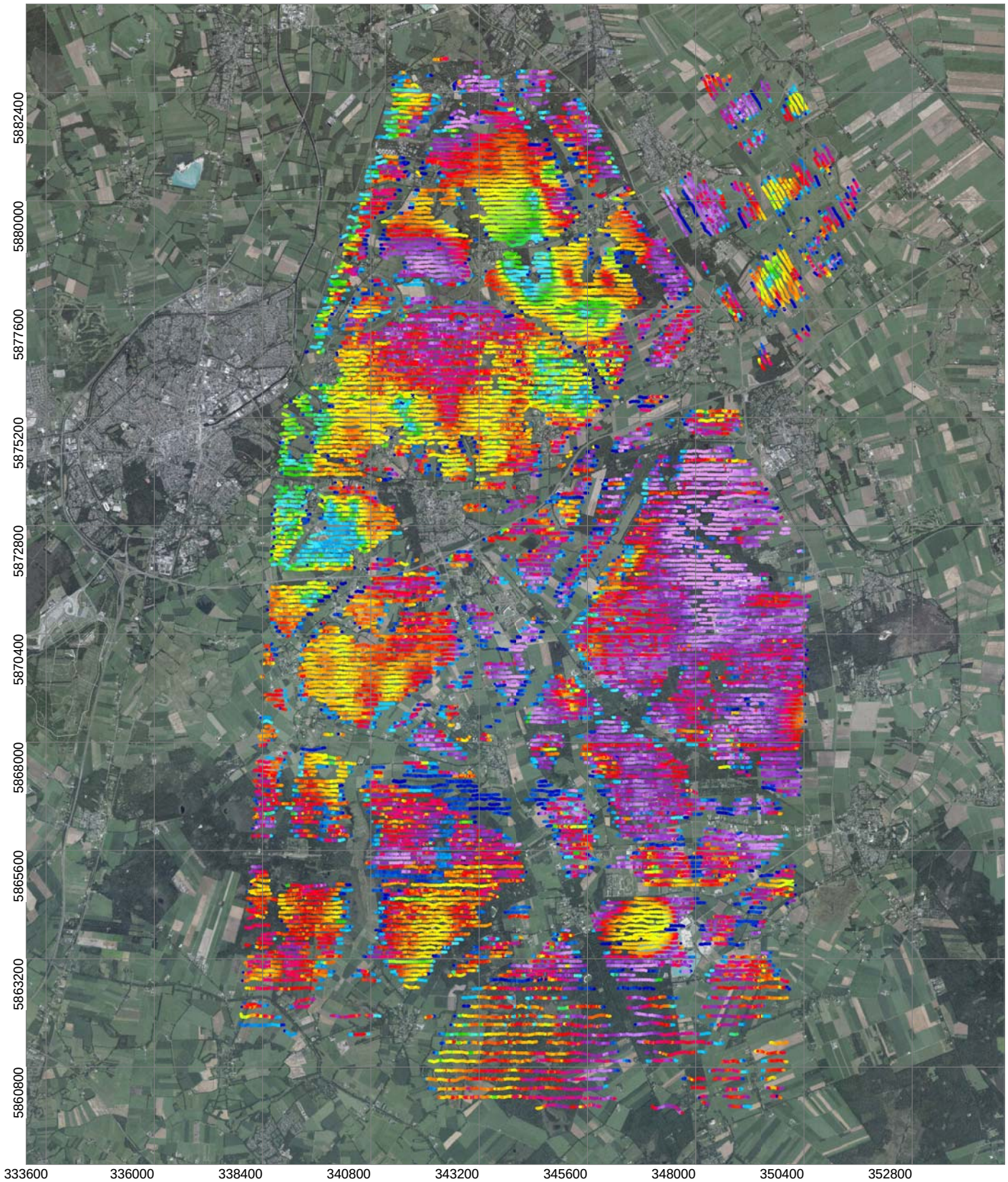
100 150 200 250 300 350
Depth [m]

Depth of Investigation, Standard

Depth, Meters

UTM 32N WGS84

5 km



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50 100 150 200 250
Depth [m]

Depth of Investigation, Conservative

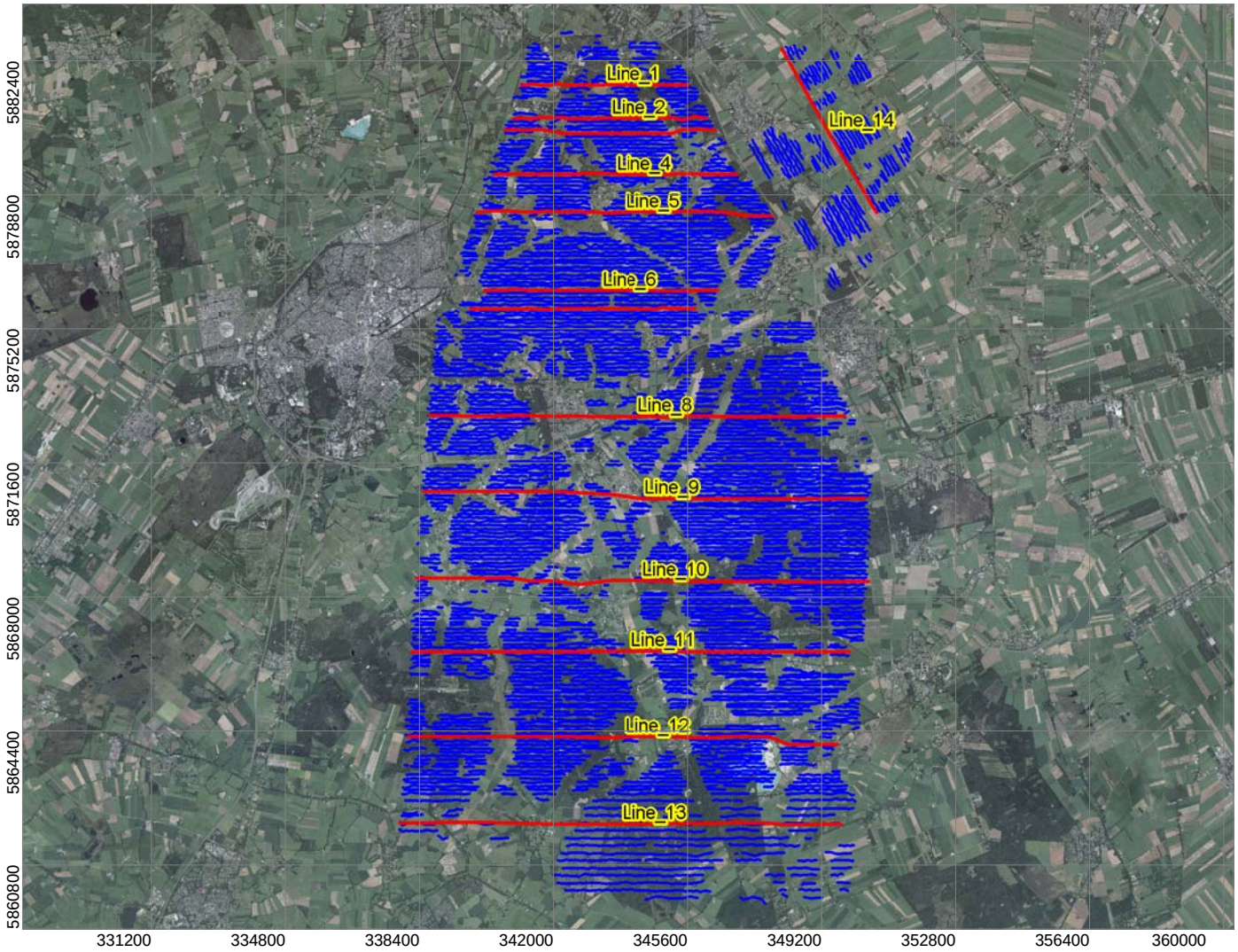
Depth, Meters

UTM 32N WGS84

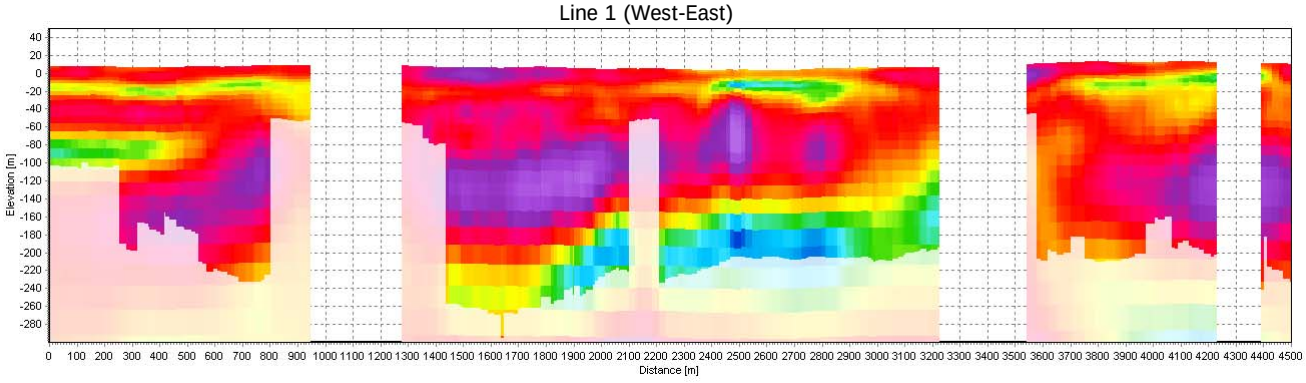
5 km

APPENDIX II: CROSS SECTIONS

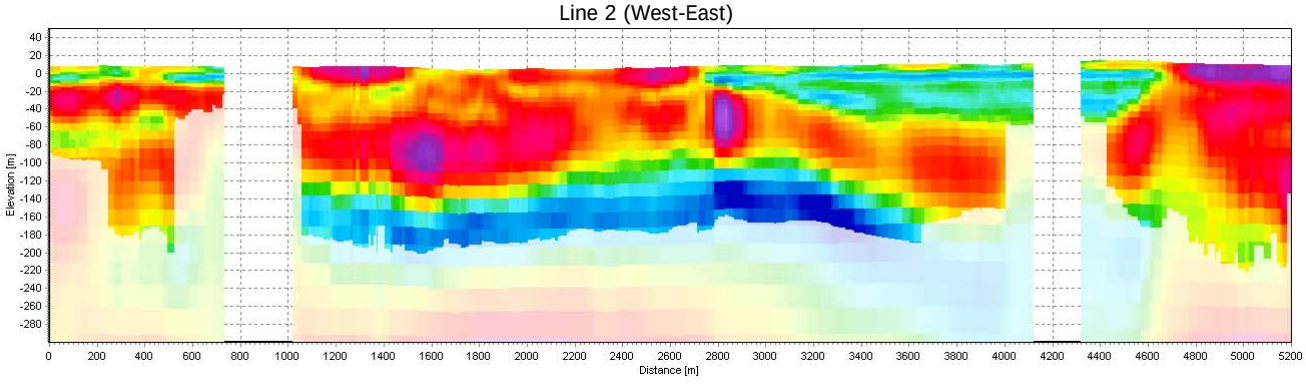
Selected cross sections for the smooth inversion are included. Each section holds the model bars blanked at the DOI- standard value. Sections for all the flight line are available in the delivered Work-space.



Line 1 (West-East)



Line 2 (West-East)



SkyTEM Survey Drenthe 2017

Resistivity Profiles (ohm-m)

Smooth SCI Model

10 100 1,000

[Ohmm]

The profiles display model bars from the smooth inversion results
Models have been blanked by 75% below the DOI Standard

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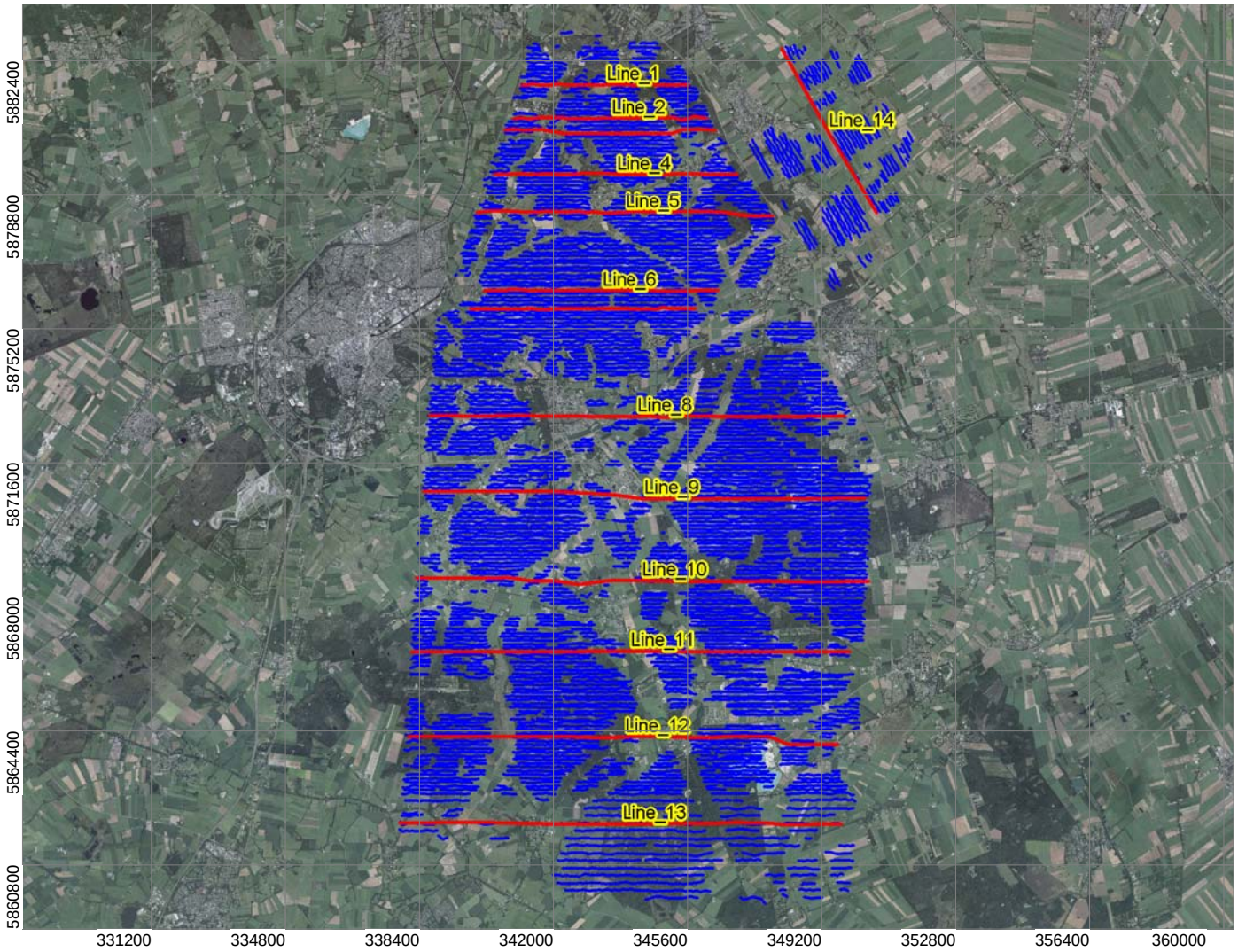
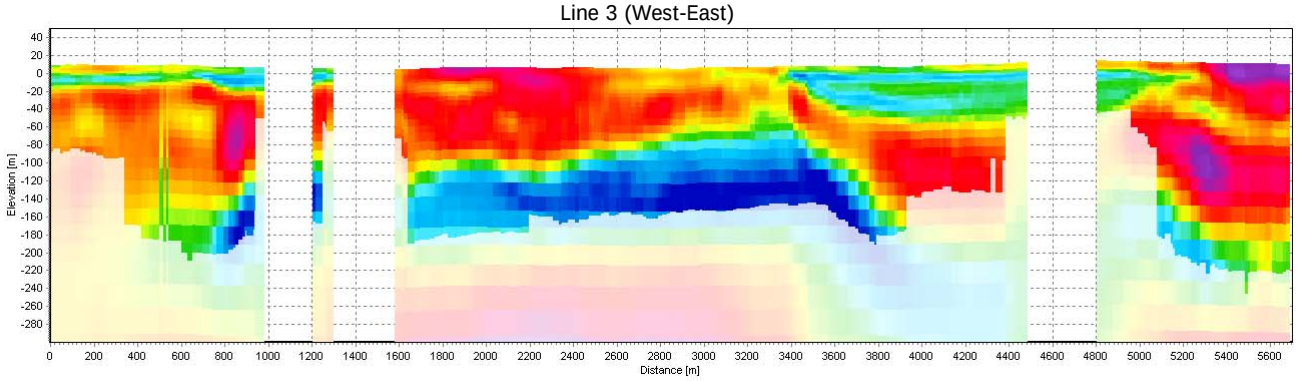
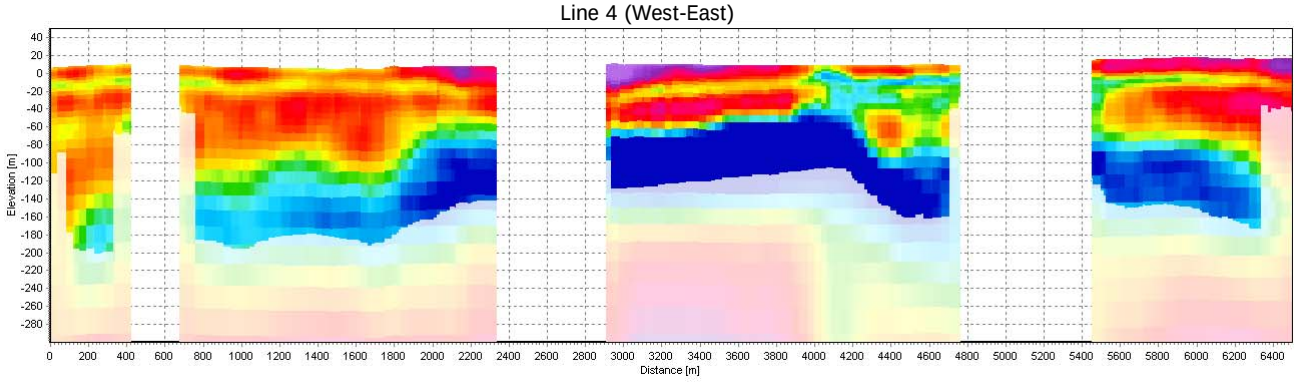


Line 3 (West-East)



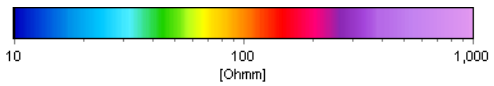
Line 4 (West-East)



SkyTEM Survey Drenthe 2017

Resistivity Profiles (ohm-m)

Smooth SCI Model



The profiles display model bars from the smooth inversion results
Models have been blanked by 75% below the DOI Standard

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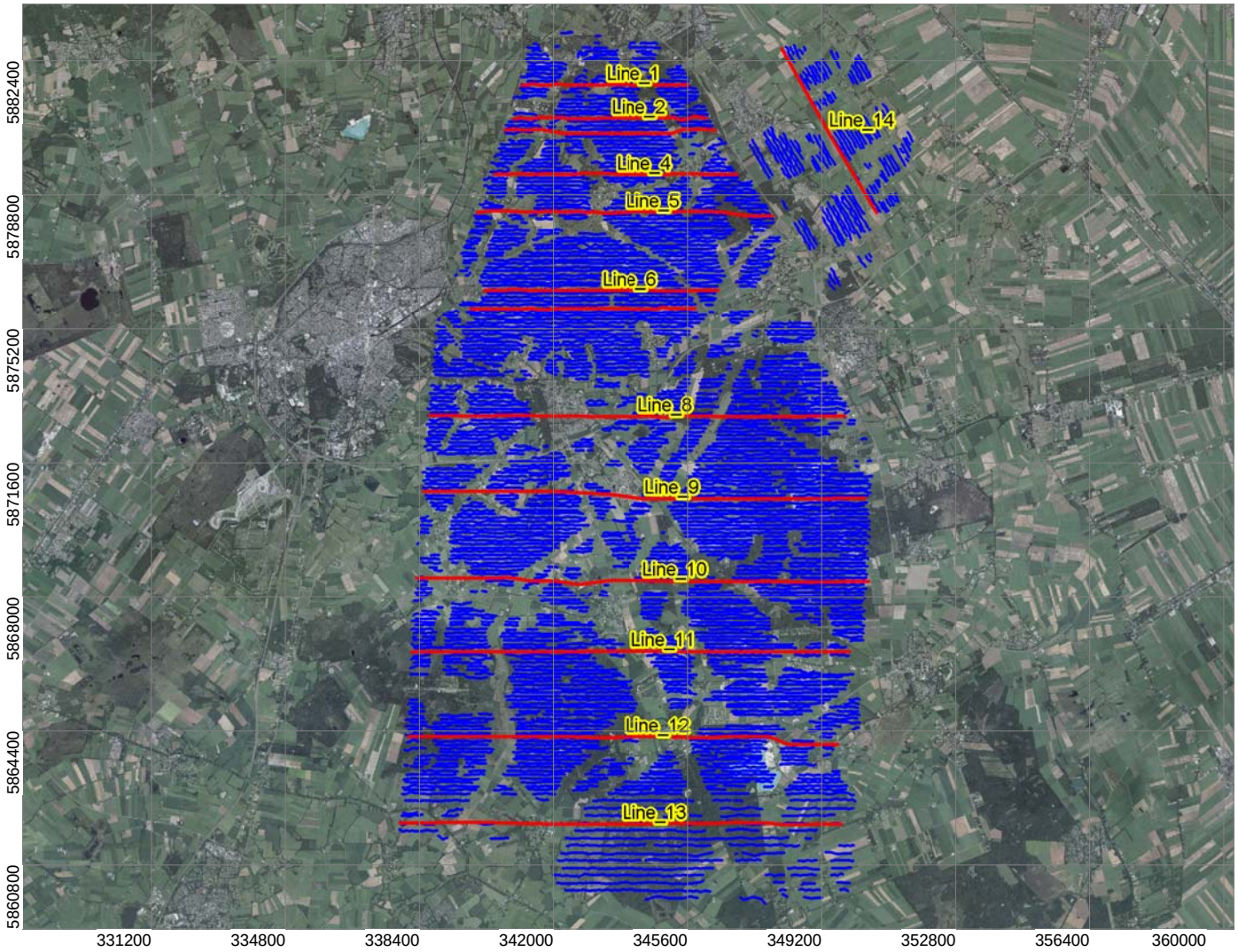
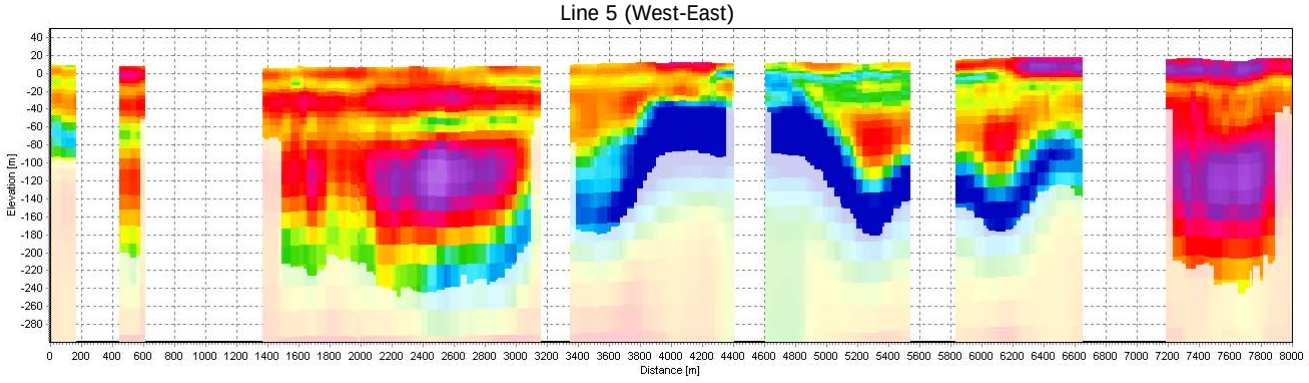
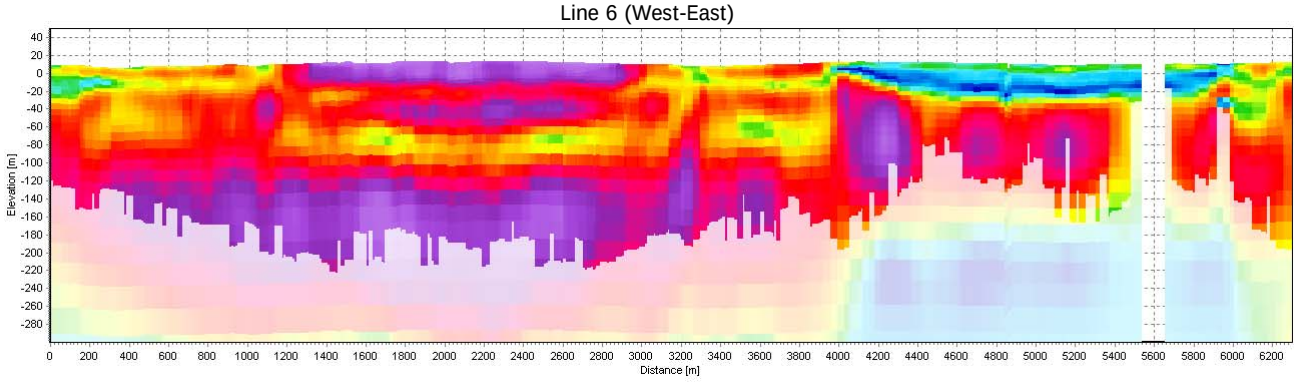


Line 5 (West-East)



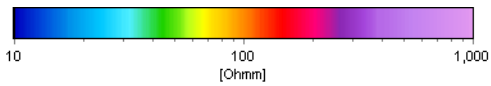
Line 6 (West-East)



SkyTEM Survey Drenthe 2017

Resistivity Profiles (ohm-m)

Smooth SCI Model



The profiles display model bars from the smooth inversion results
Models have been blanked by 75% below the DOI Standard

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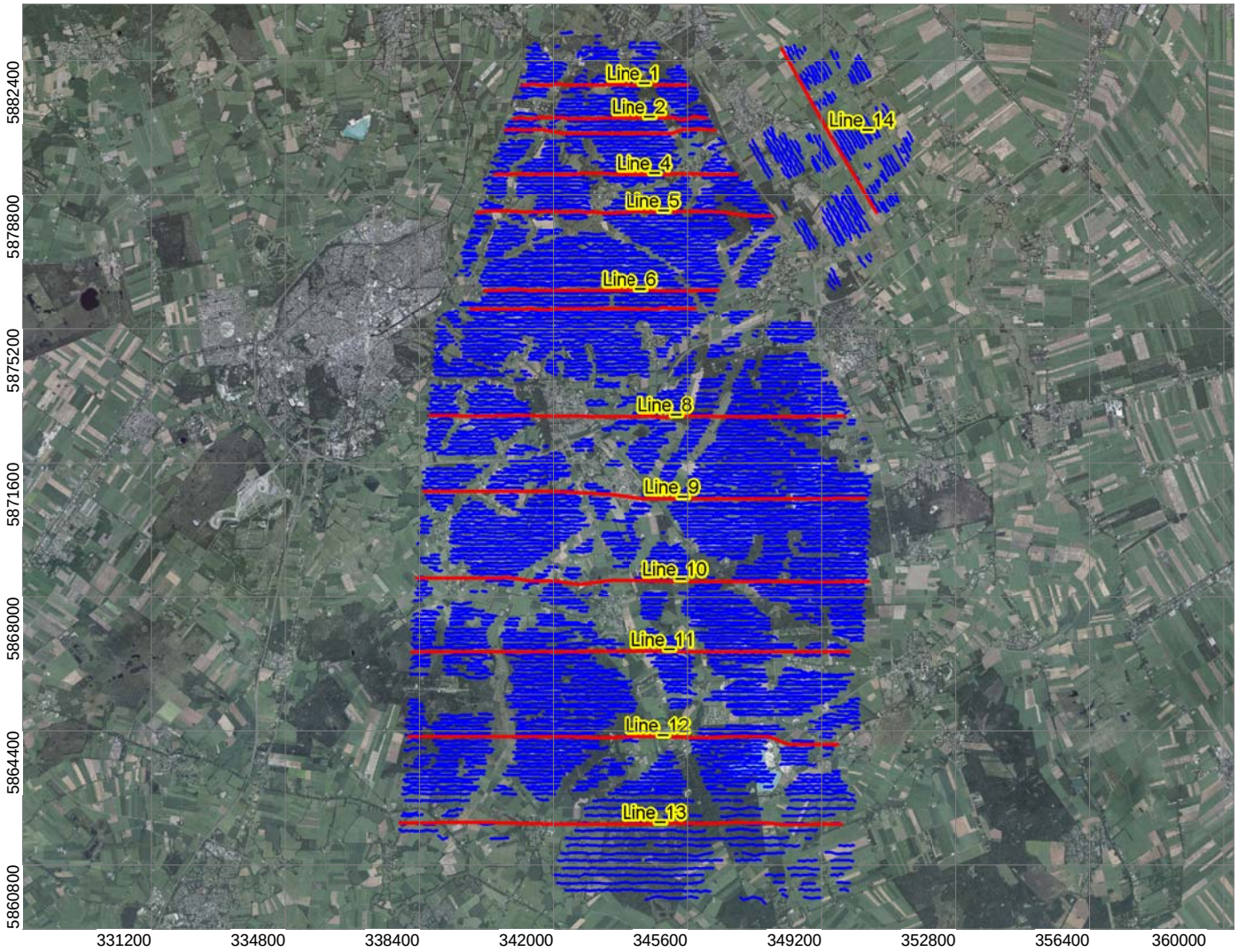
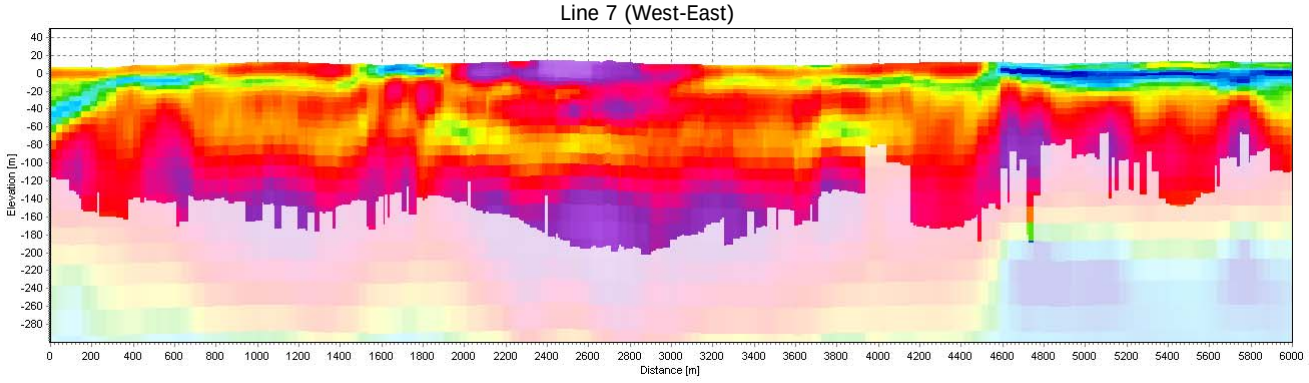
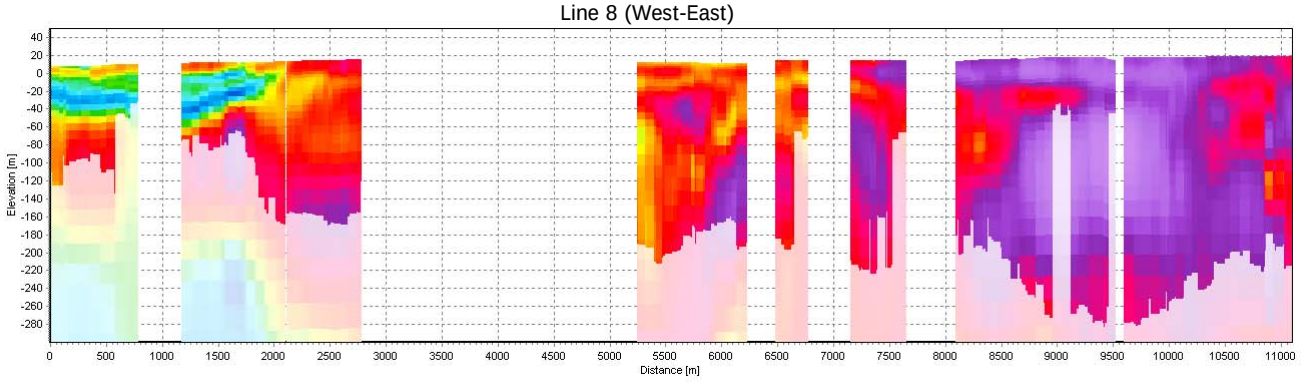


Line 7 (West-East)



Line 8 (West-East)



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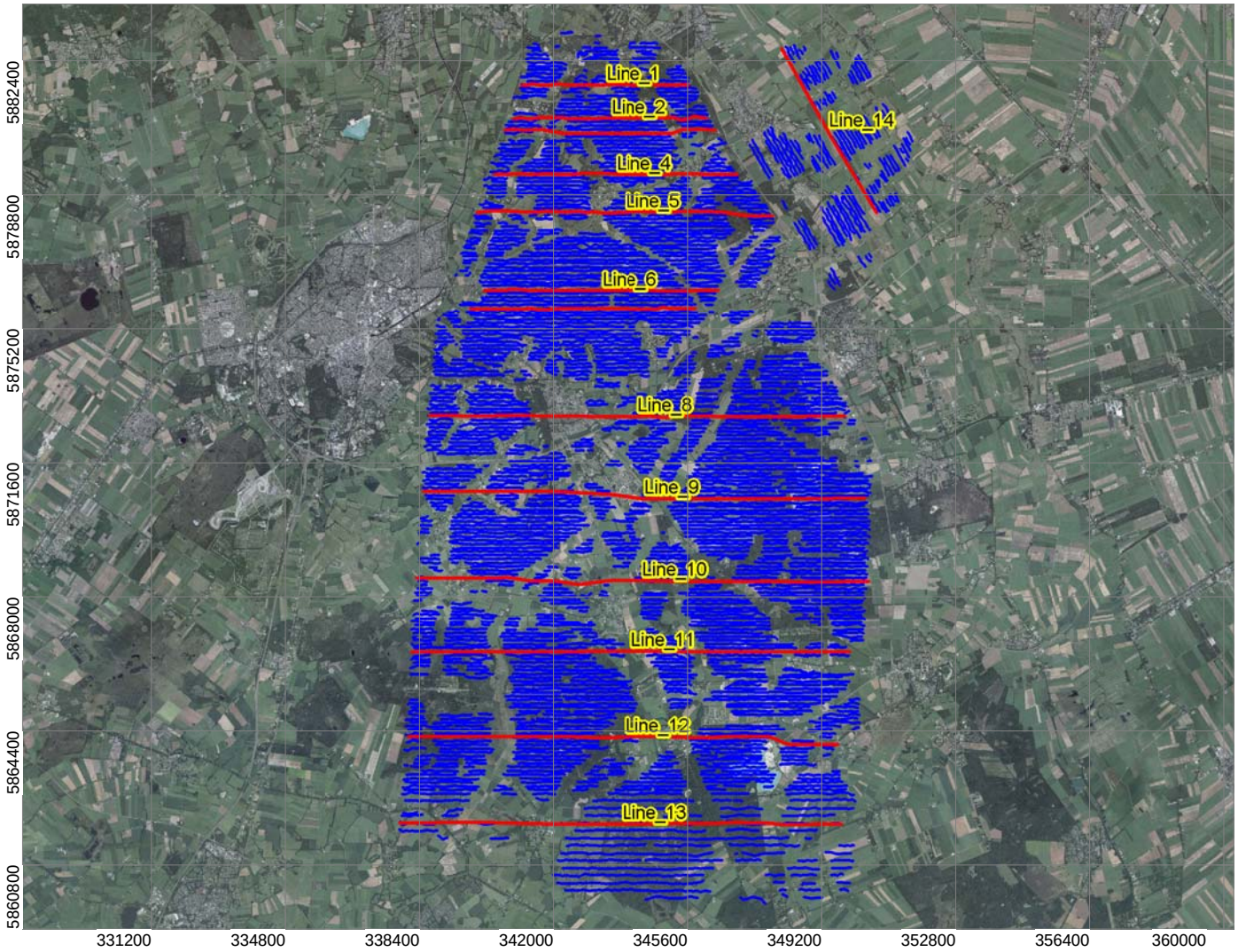
Resistivity Profiles (ohm-m)

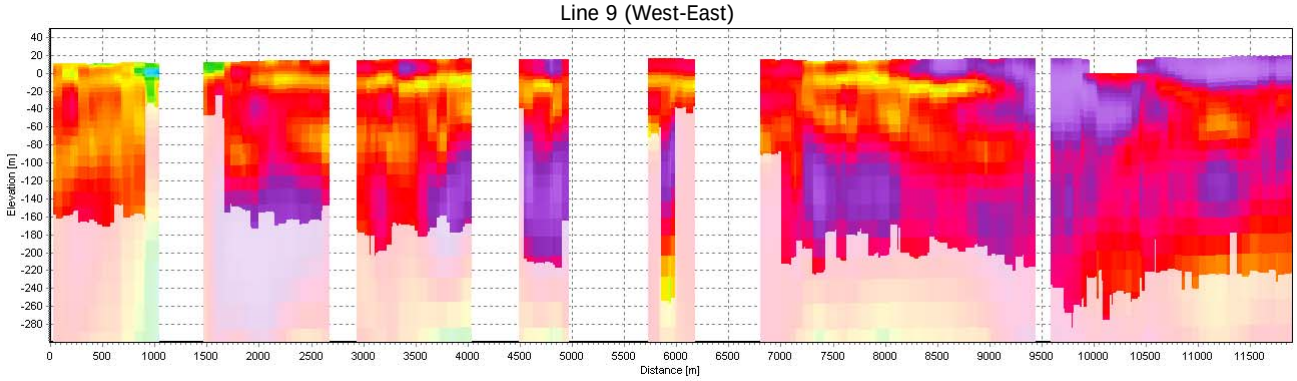
Smooth SCI Model

10 — 100 — 1,000
[Ohmm]

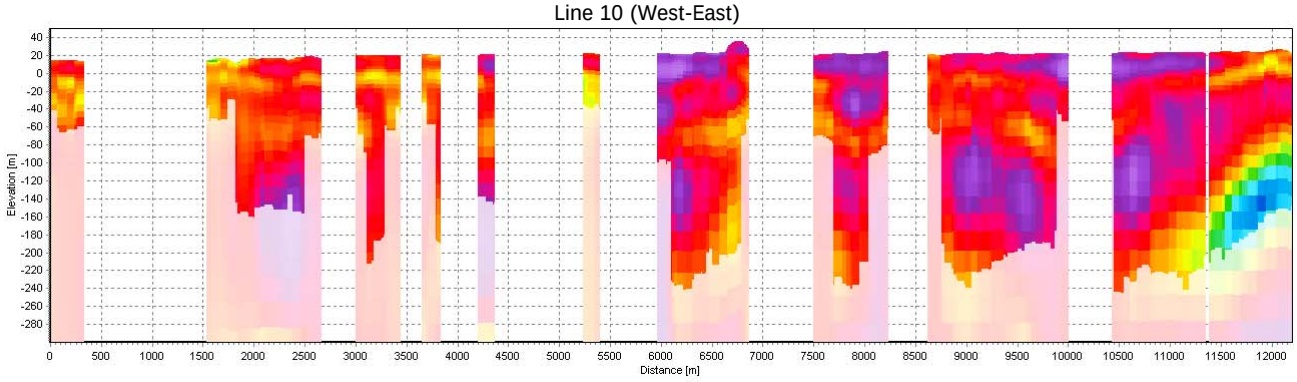
The profiles display model bars from the smooth inversion results
Models have been blanked by 75% below the DOI Standard



Line 9 (West-East)



Line 10 (West-East)



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Resistivity Profiles (ohm-m)

Smooth SCI Model

10 100 1,000

[Ohmm]

The profiles display model bars from the smooth inversion results
Models have been blanked by 75% below the DOI Standard

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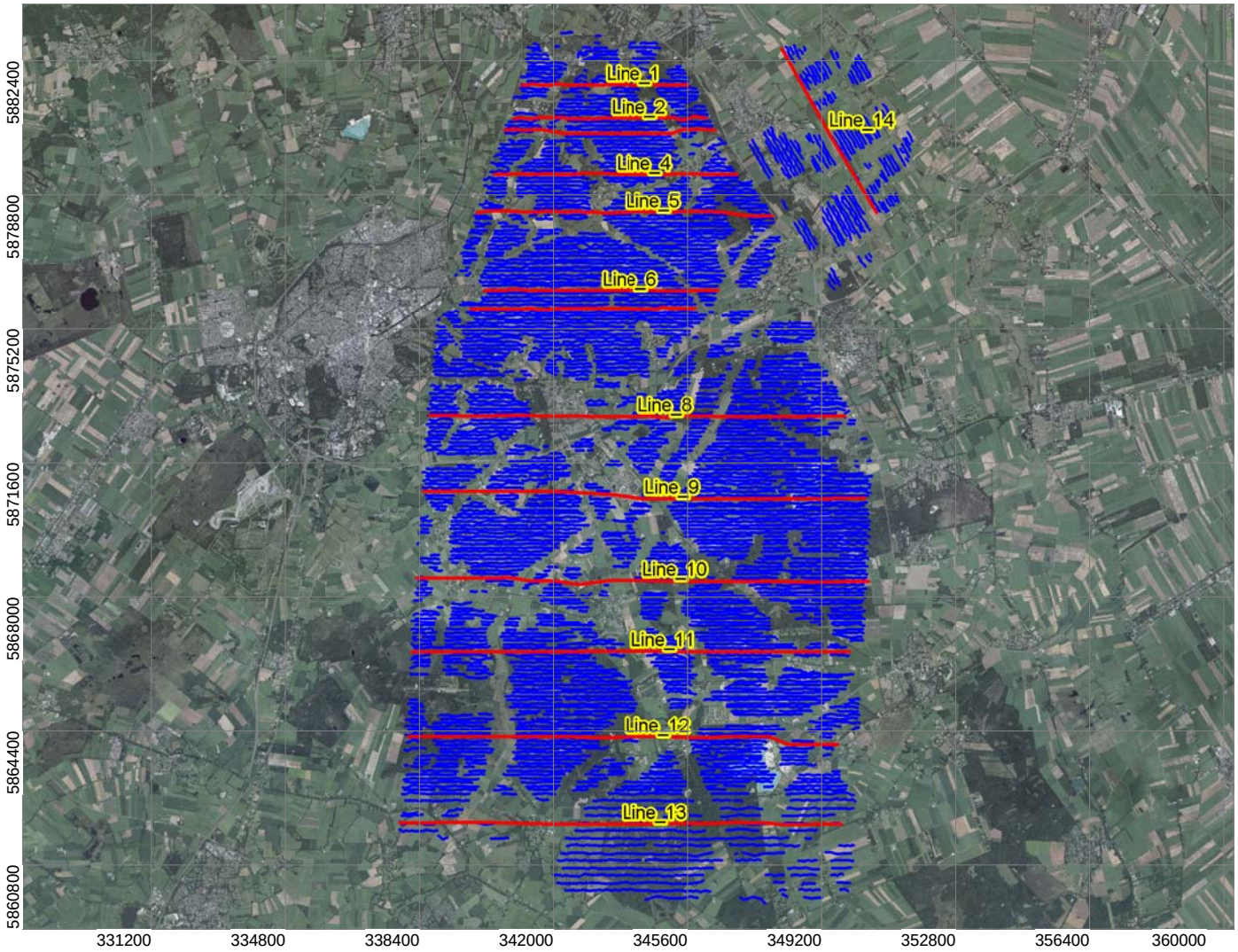
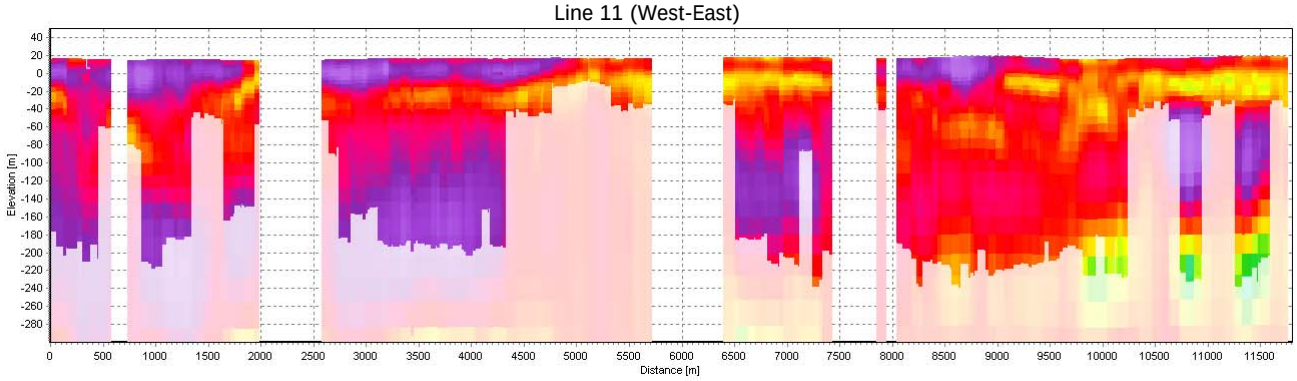
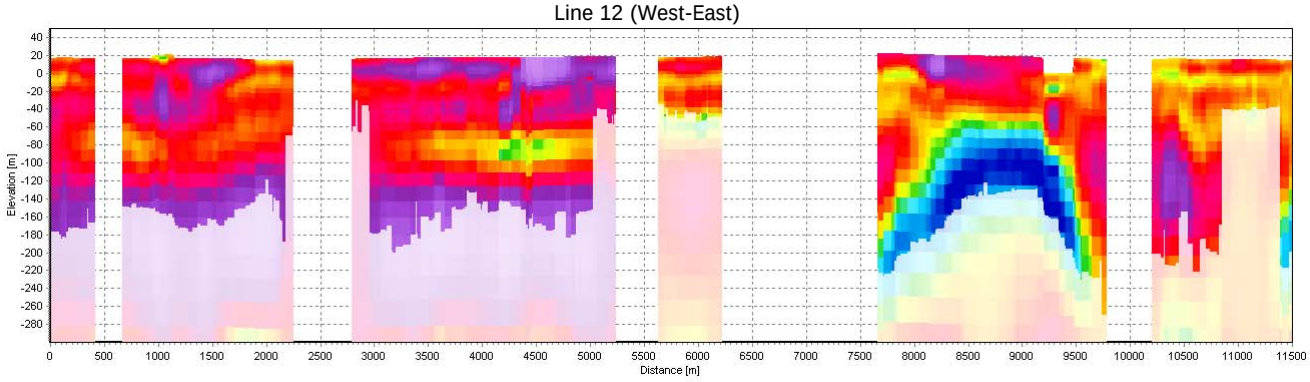


Line 11 (West-East)



Line 12 (West-East)



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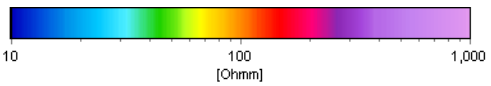
Resistivity Profiles (ohm-m)

Smooth SCI Model



The profiles display model bars from the smooth inversion results
Models have been blanked by 75% below the DOI Standard

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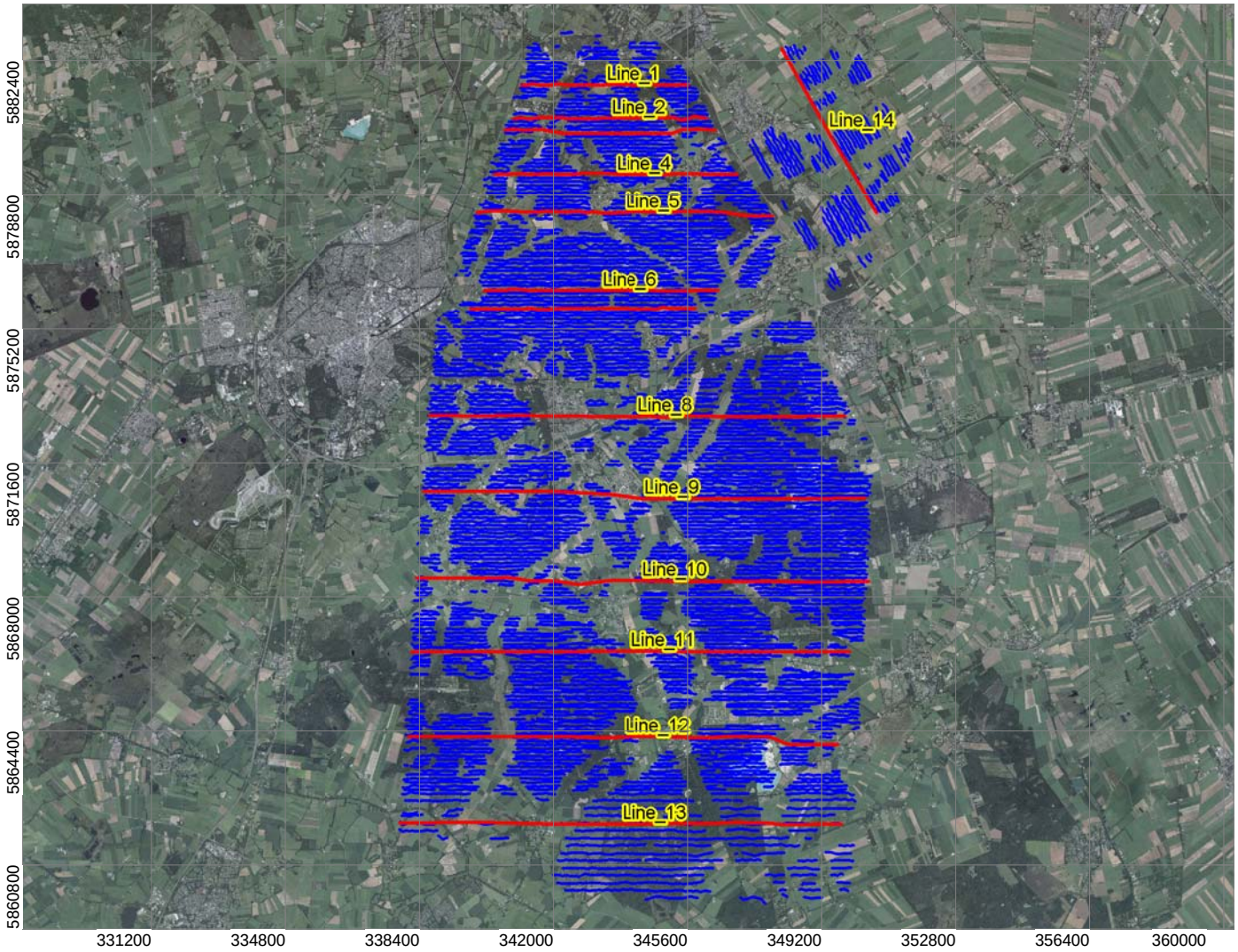
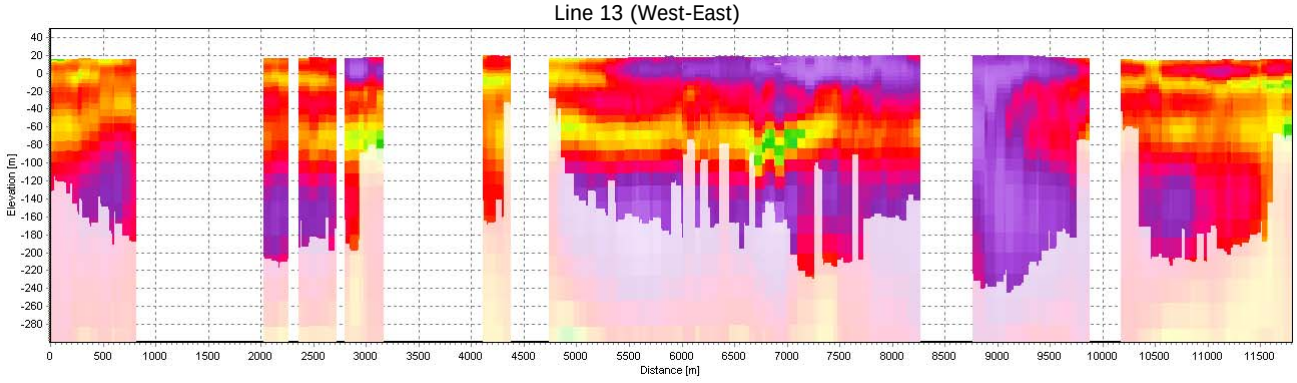
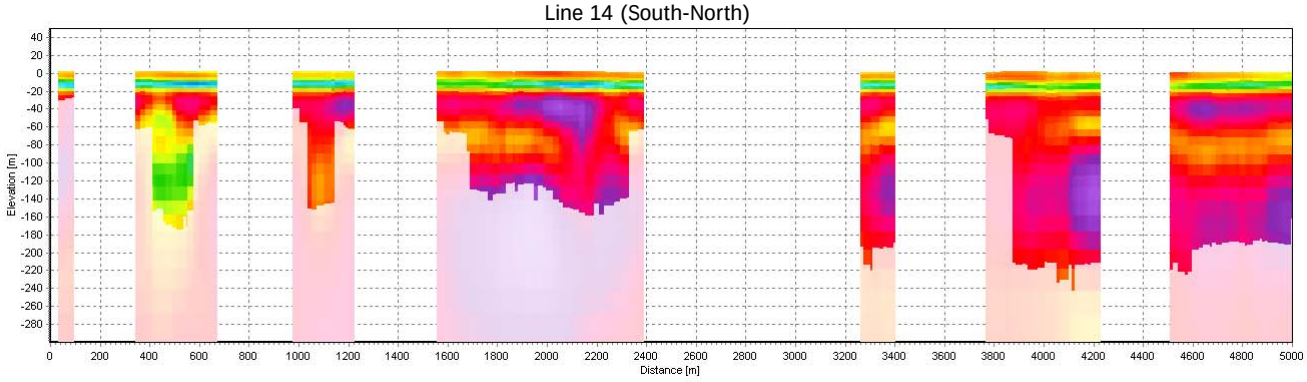


Line 13 (West-East)



Line 14 (South-North)



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Resistivity Profiles (ohm-m)

Smooth SCI Model

10 100 1,000

[Ohmm]

The profiles display model bars from the smooth inversion results
Models have been blanked by 75% below the DOI Standard

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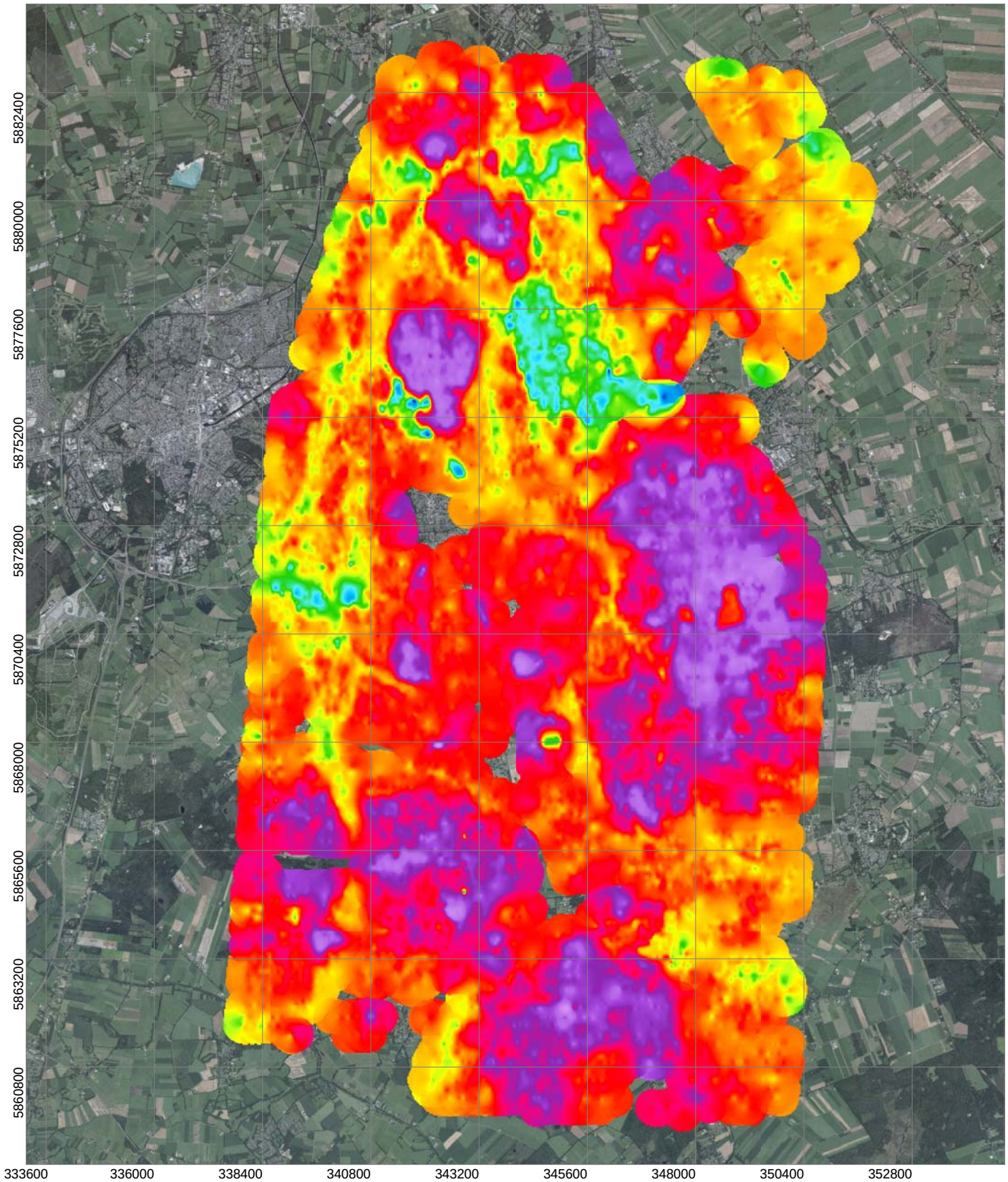
APPENDIX III: MEAN RESISTIVITY MAPS

This appendix includes mean resistivity maps generated from the smooth model inversion result in 5 m depth intervals from 0 to 50 m, and in 10 m intervals from 50 to 300 m. The resistivity models have been blanked at the DOI standard value prior to the interpolation to regular mean resistivity grids.

The interpolation of the mean resistivity values is performed by Kriging interpolation, with a node spacing of 25 m, a search radius of 400 m, and with additional pixel smoothing in the presented bitmaps images.



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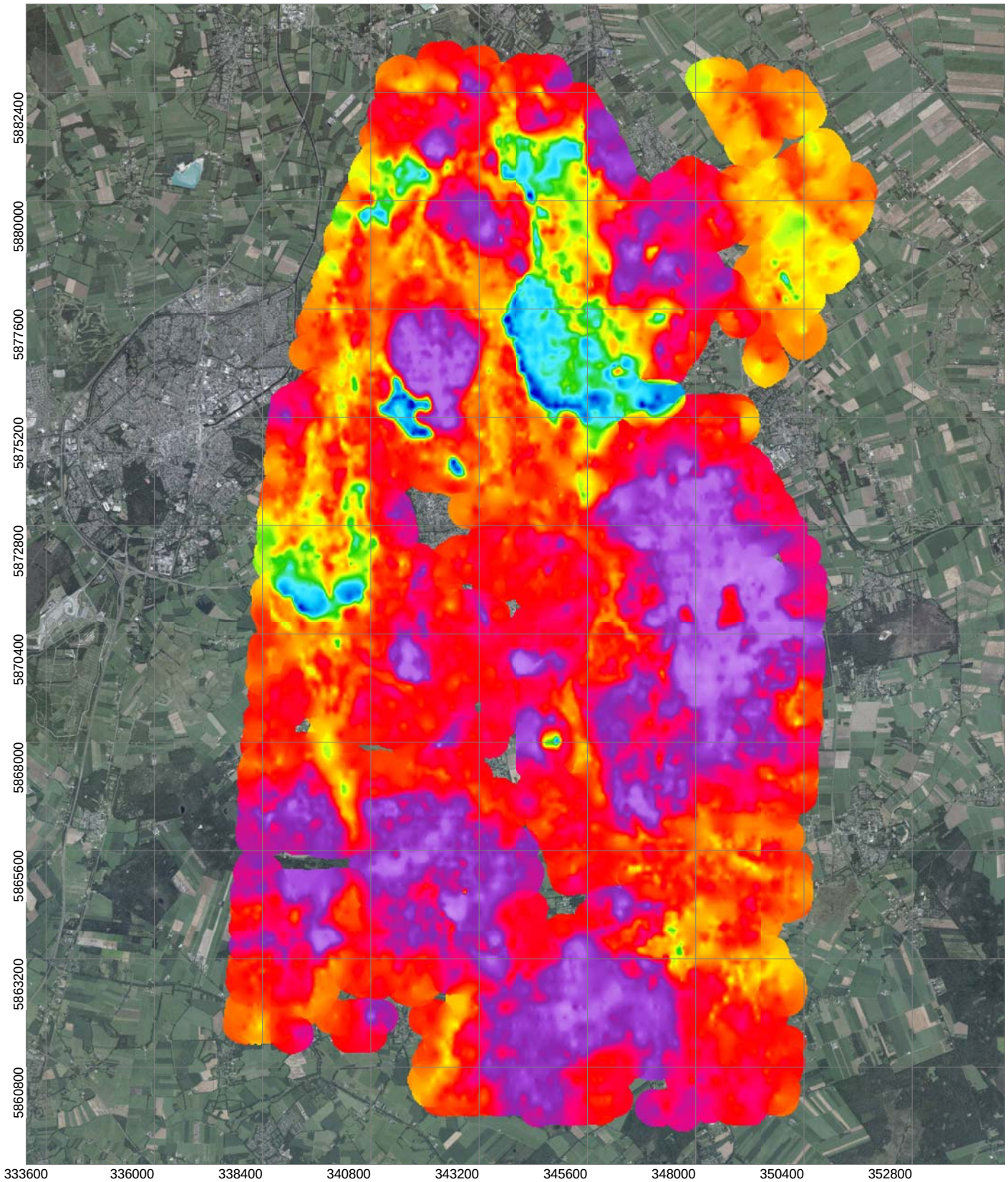
Mean Resistivity, Depth 0-5 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



SkyTEM Survey Drenthe 2017

Mean Resistivity, Depth 5-10 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000

Resistivity [Ohmm]

UTM 32N WGS84

5 km

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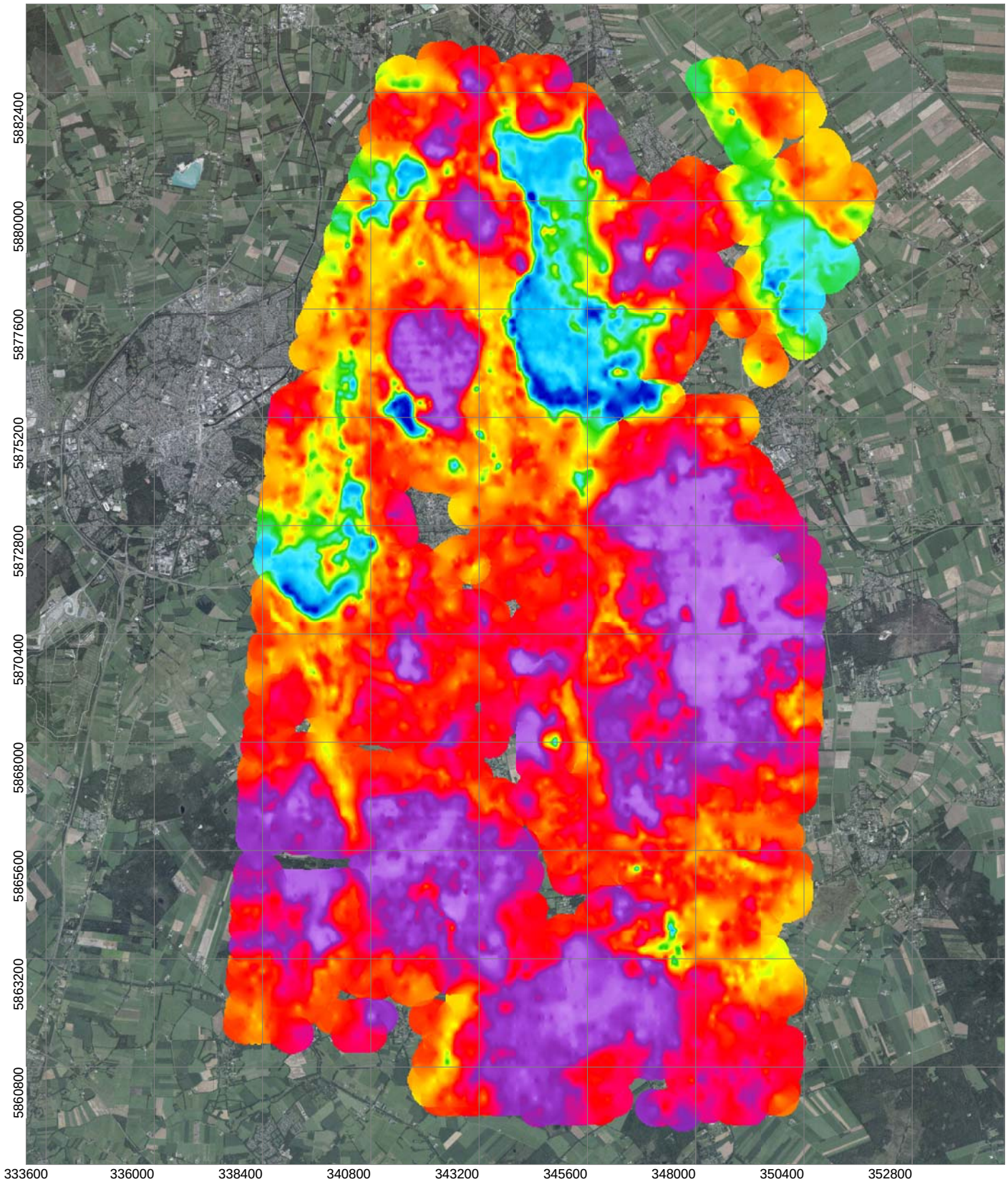

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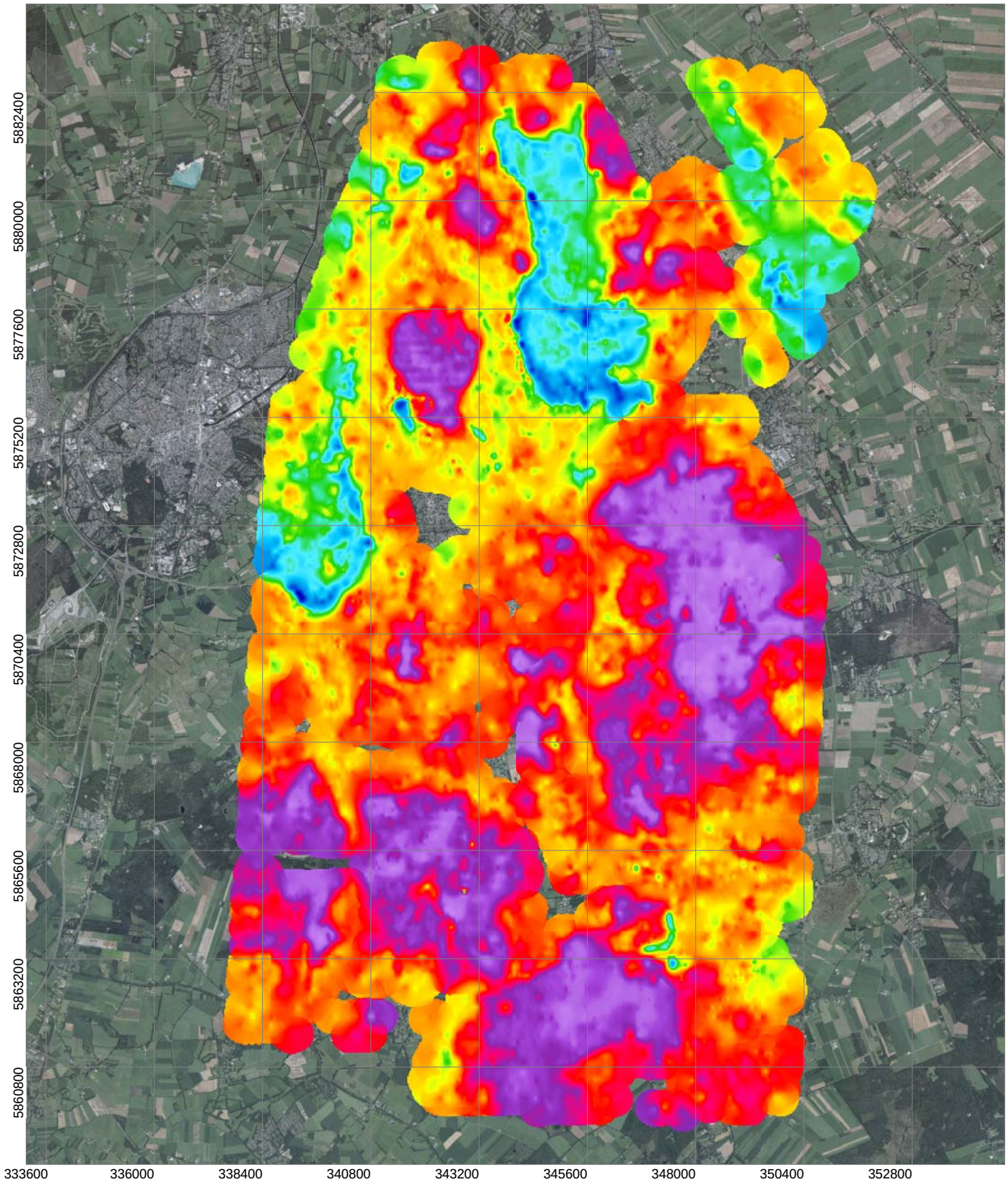
Mean Resistivity, Depth 10-15 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



SkyTEM Survey Drenthe 2017

Mean Resistivity, Depth 15-20 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000

Resistivity [Ohmm]

UTM 32N WGS84

5 km

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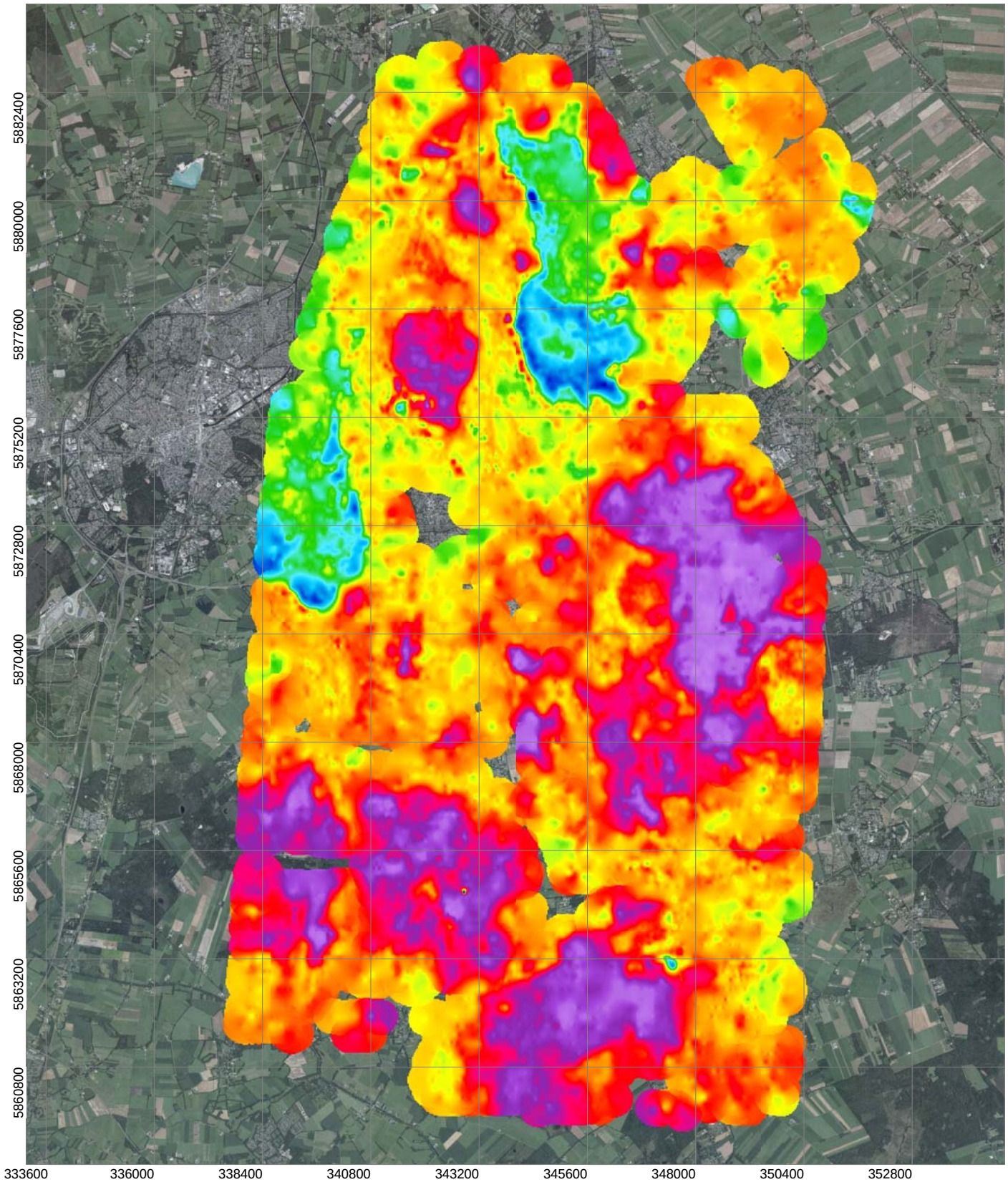

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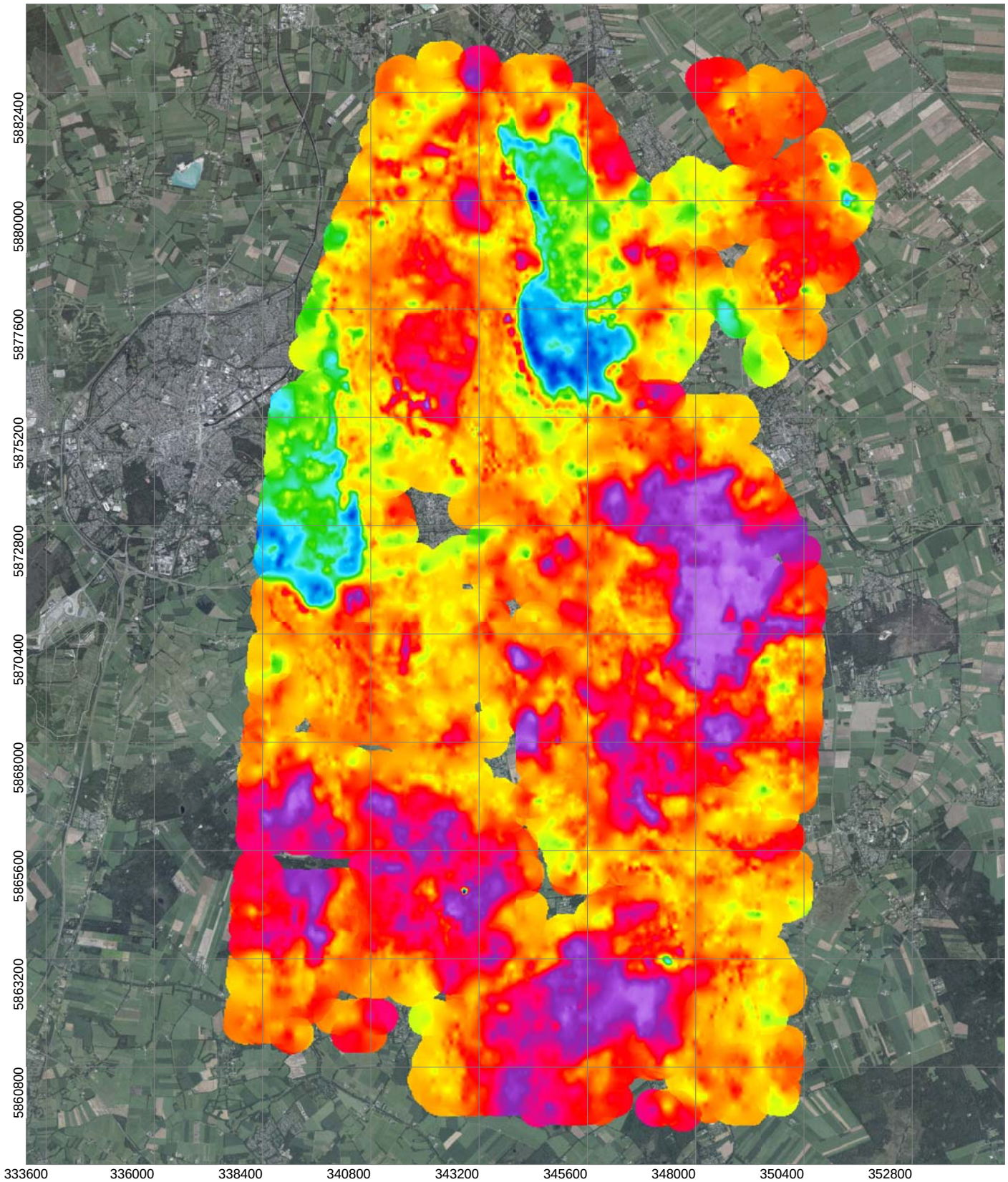
Mean Resistivity, Depth 20-25 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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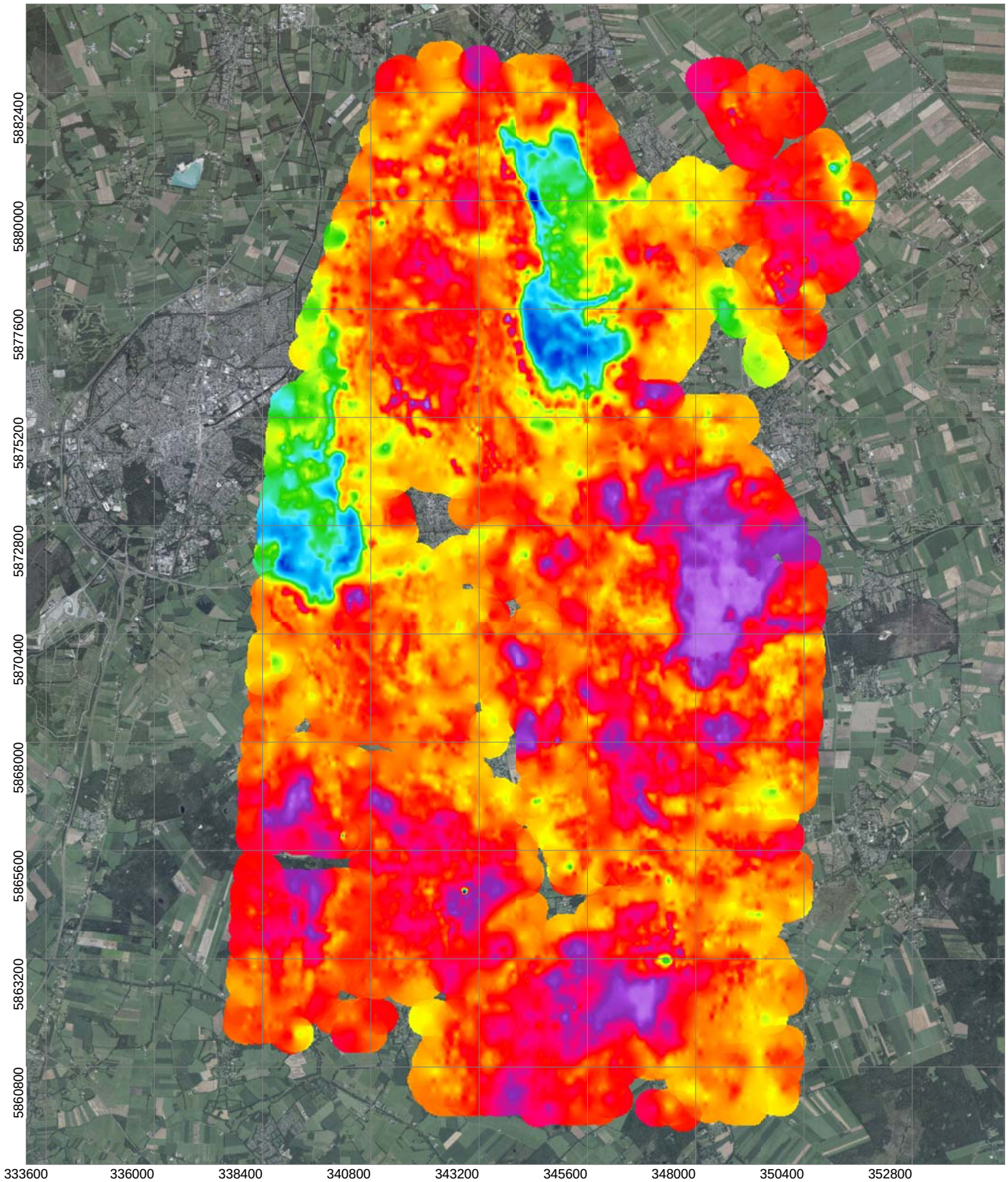
Mean Resistivity, Depth 25-30 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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SkyTEM Survey Drenthe 2017

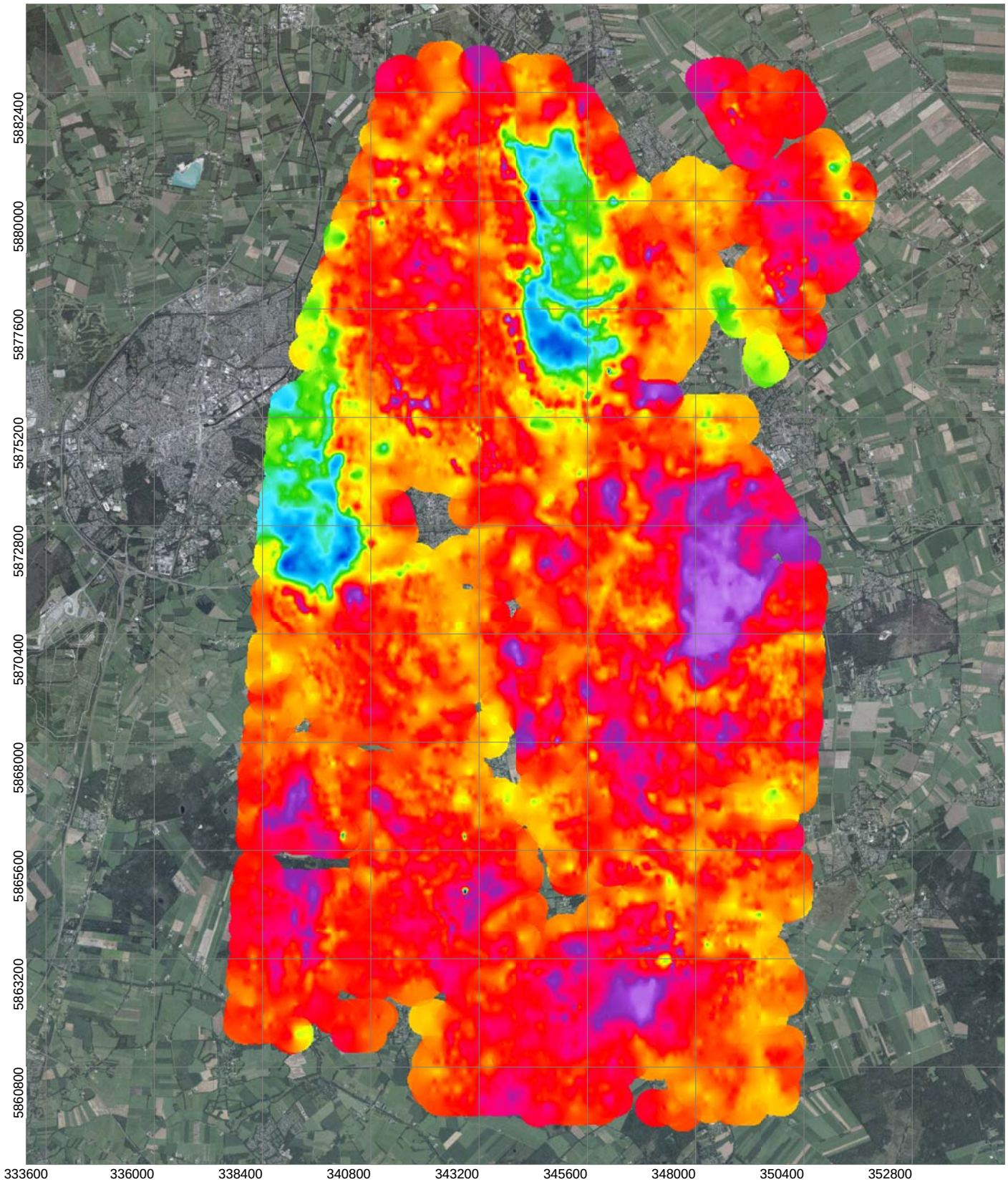
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 30-35 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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SkyTEM Survey Drenthe 2017

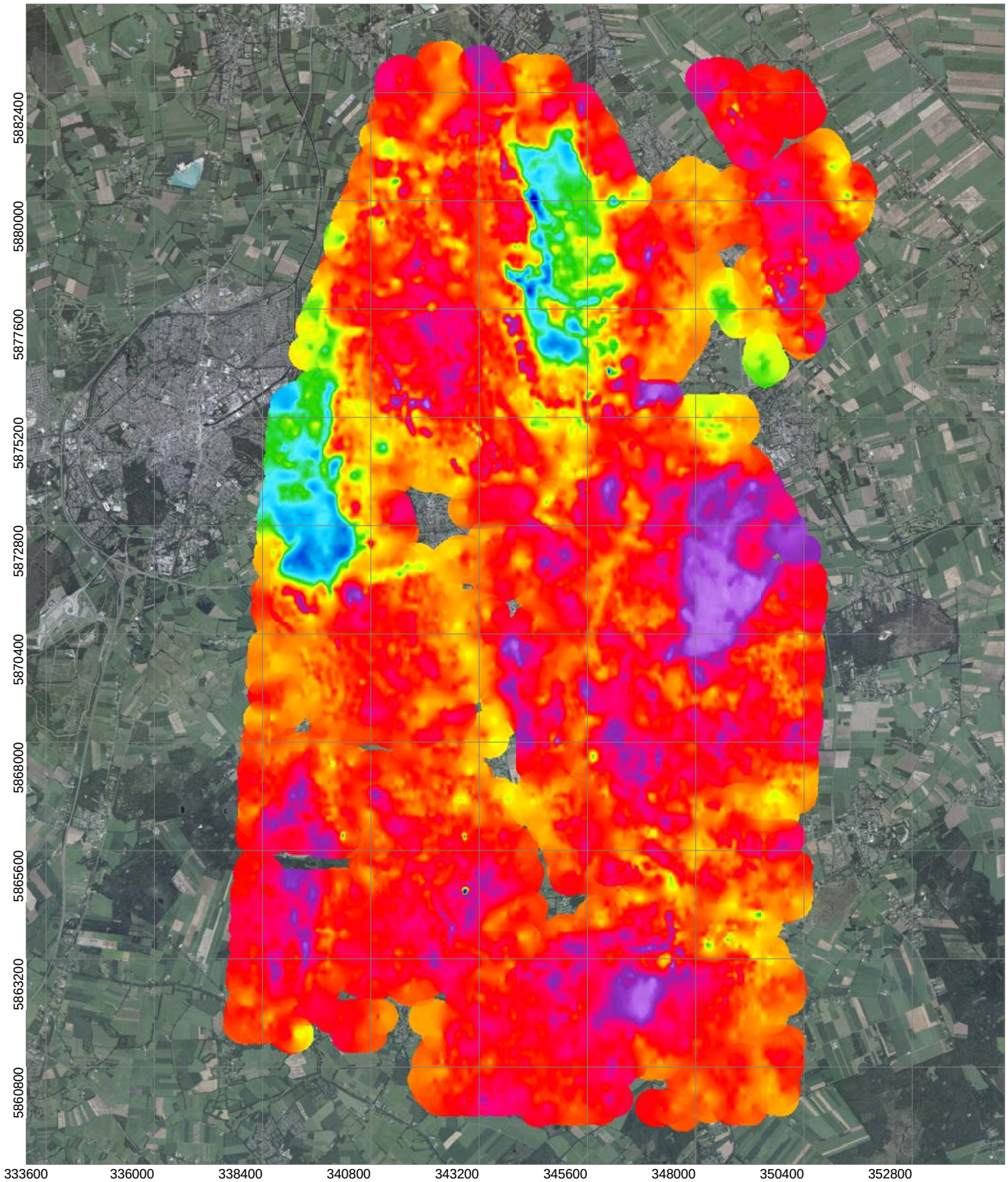
Mean Resistivity, Depth 35-40 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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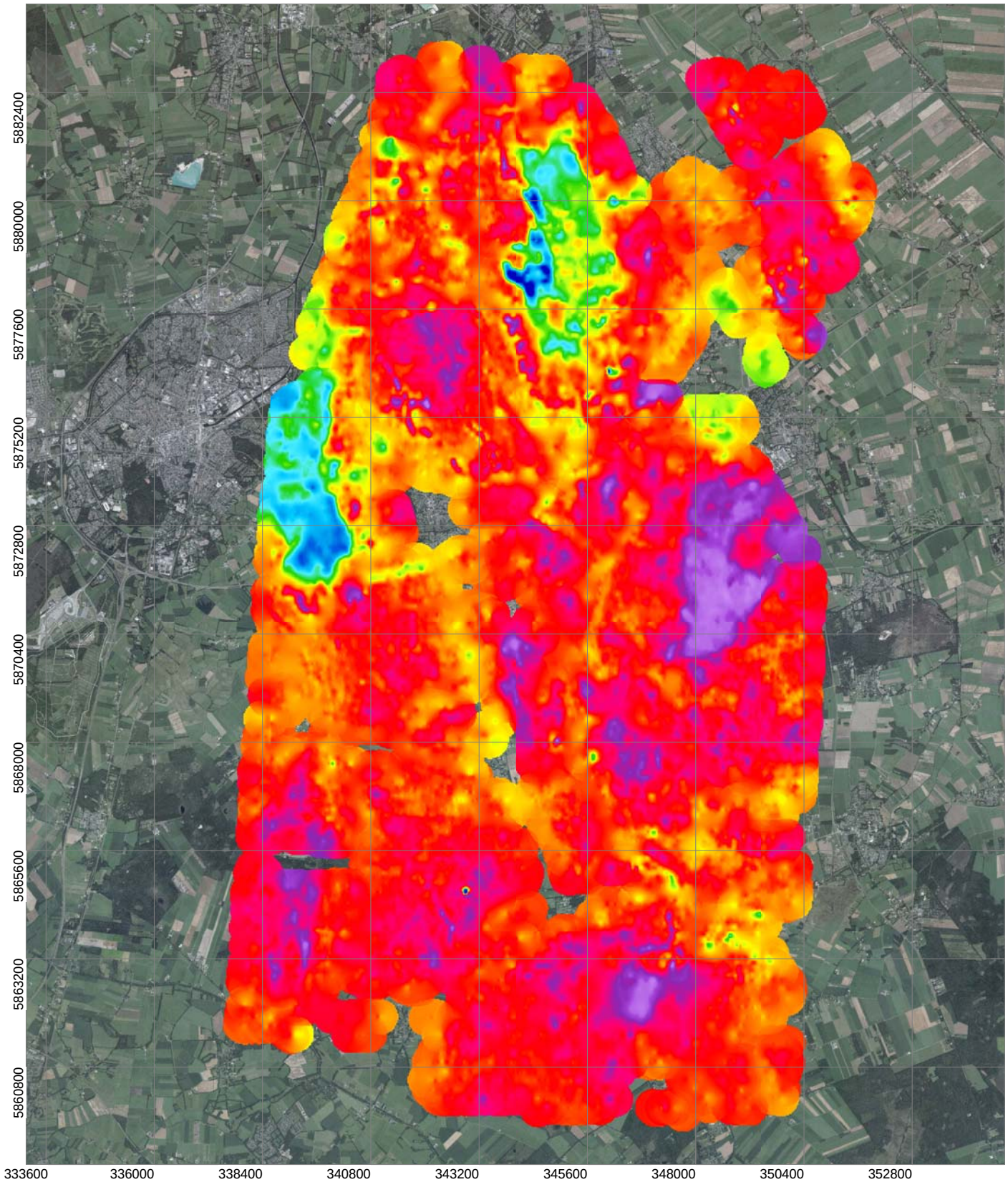
Mean Resistivity, Depth 40-45 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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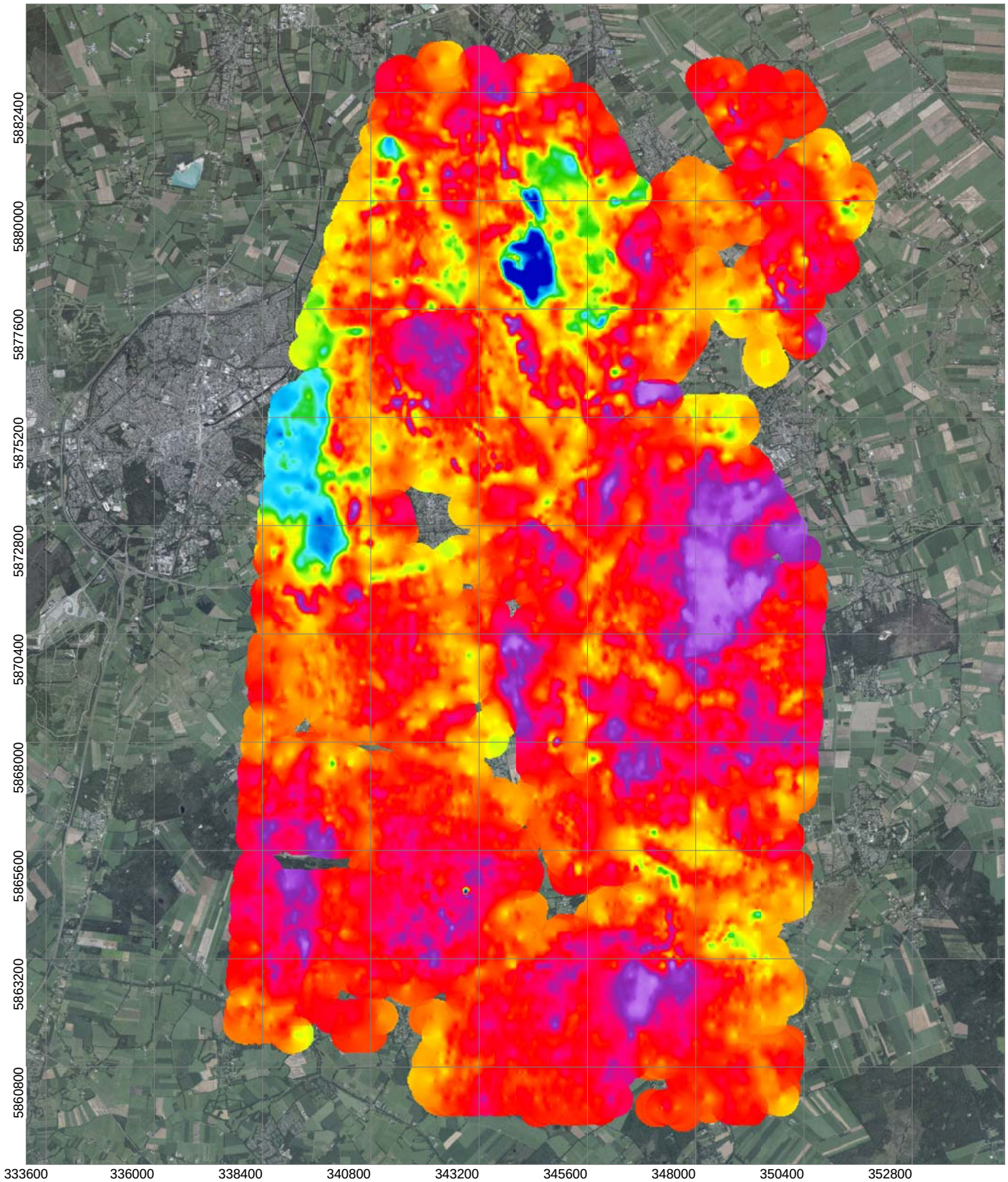
Mean Resistivity, Depth 45-50 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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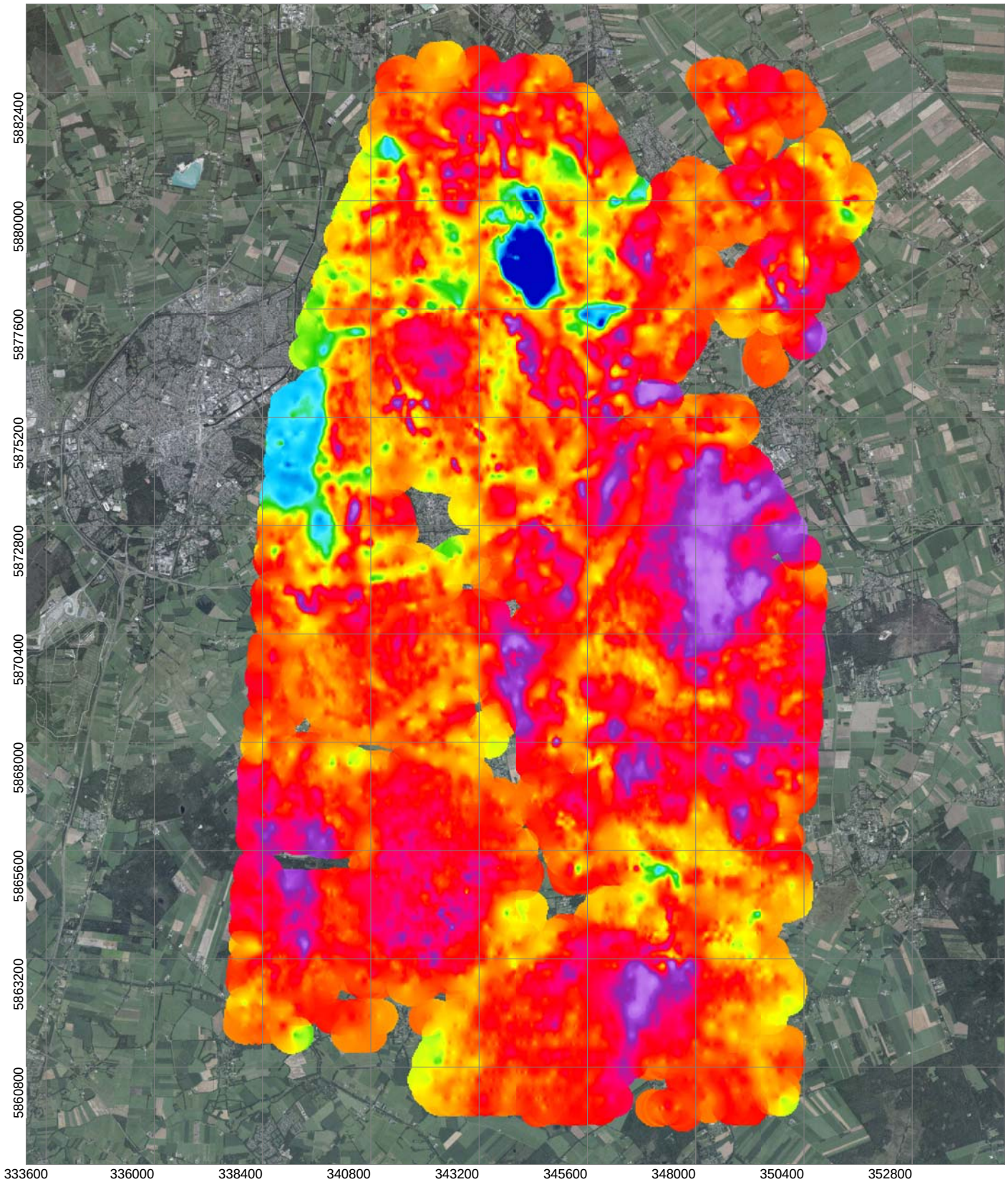
Mean Resistivity, Depth 50-60 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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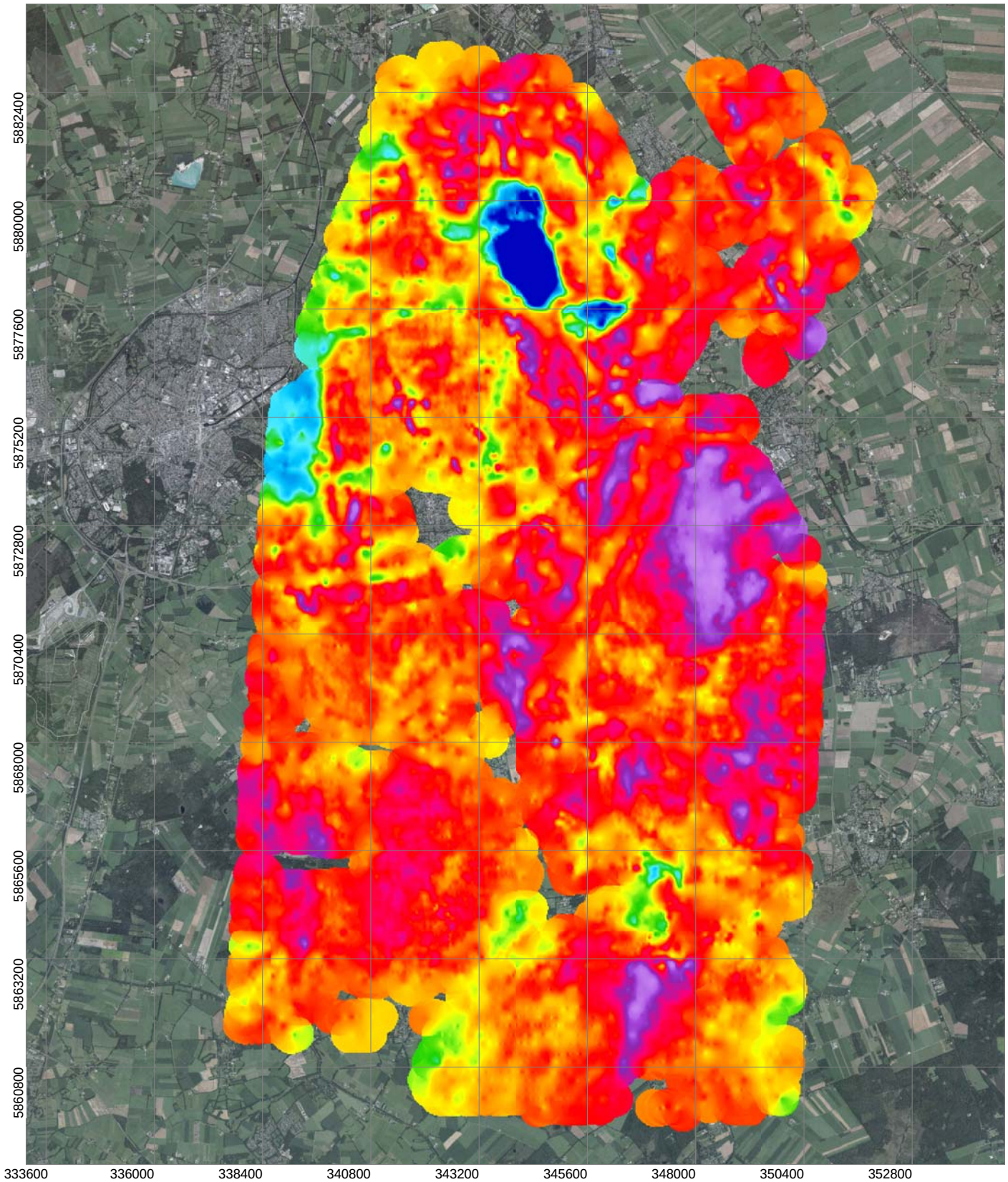
Mean Resistivity, Depth 60-70 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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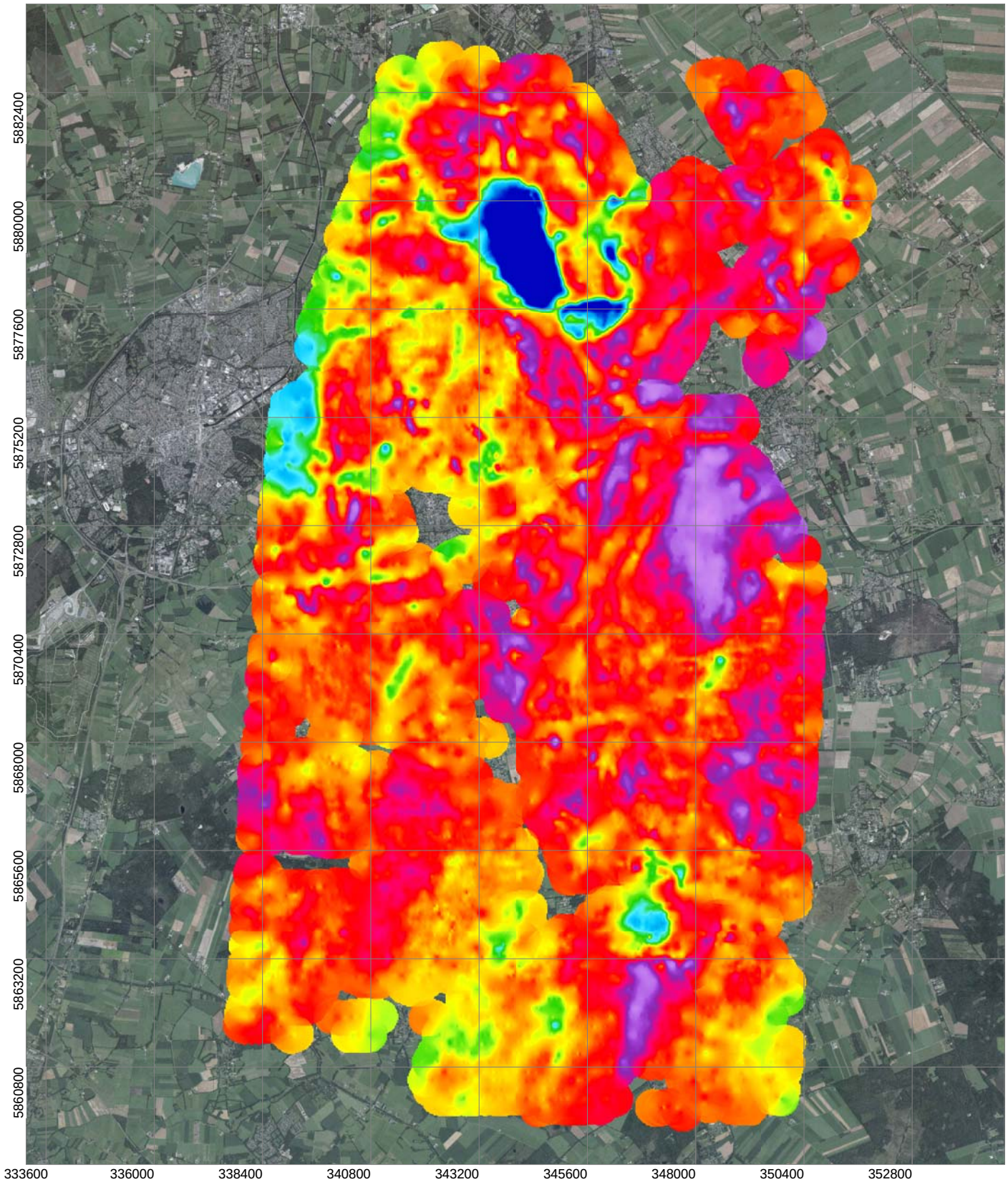
Mean Resistivity, Depth 70-80 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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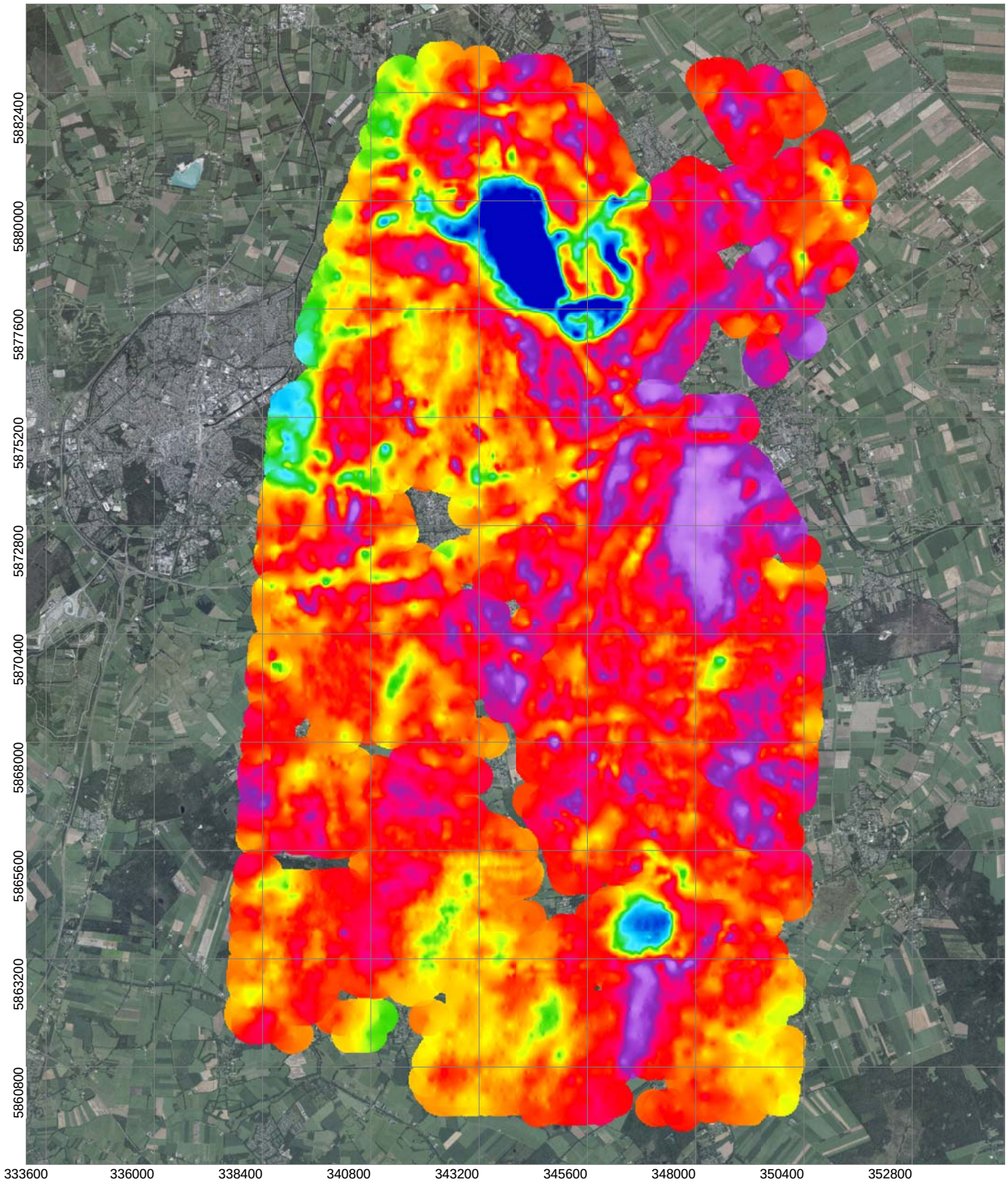
Mean Resistivity, Depth 80-90 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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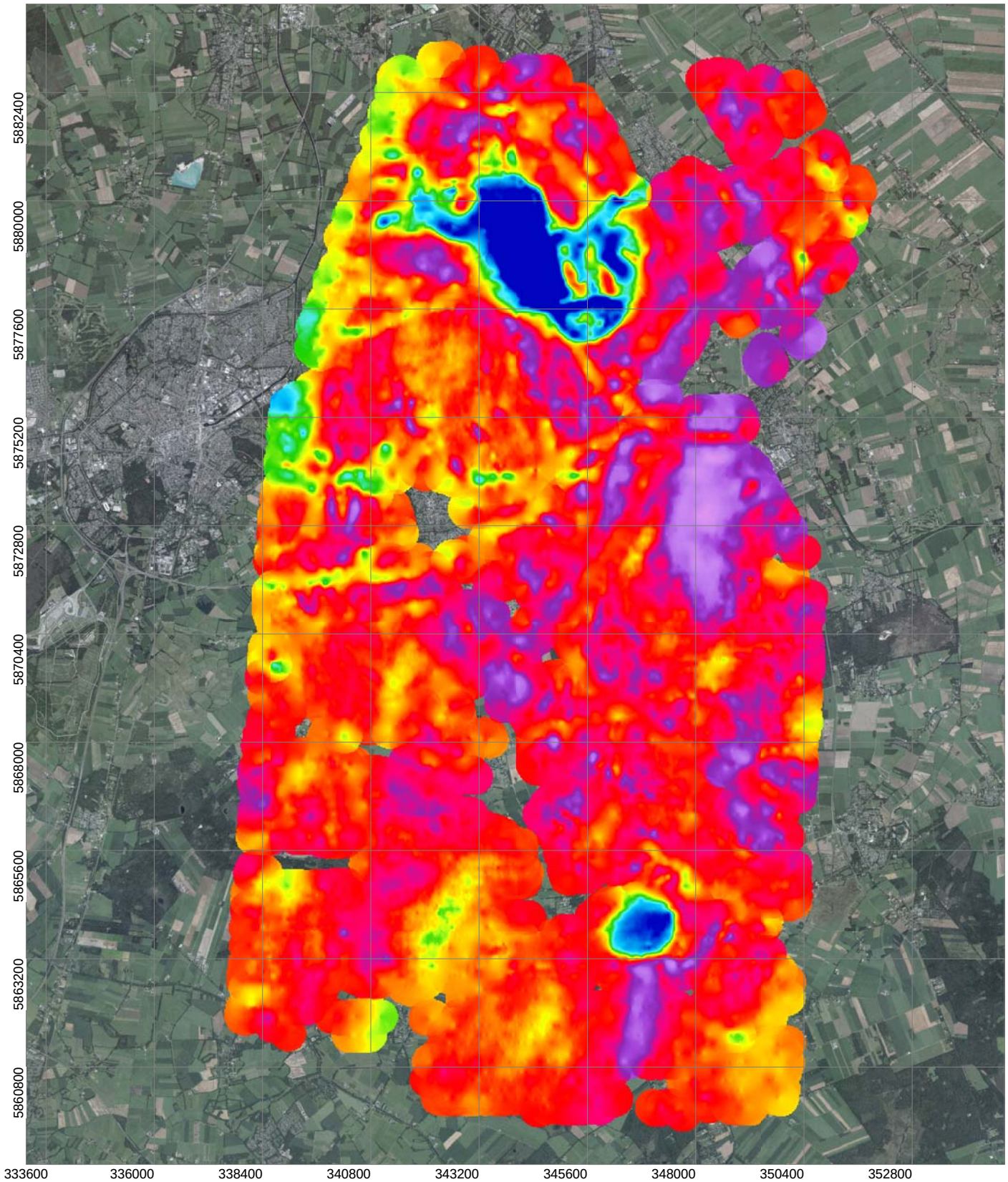
Mean Resistivity, Depth 90-100 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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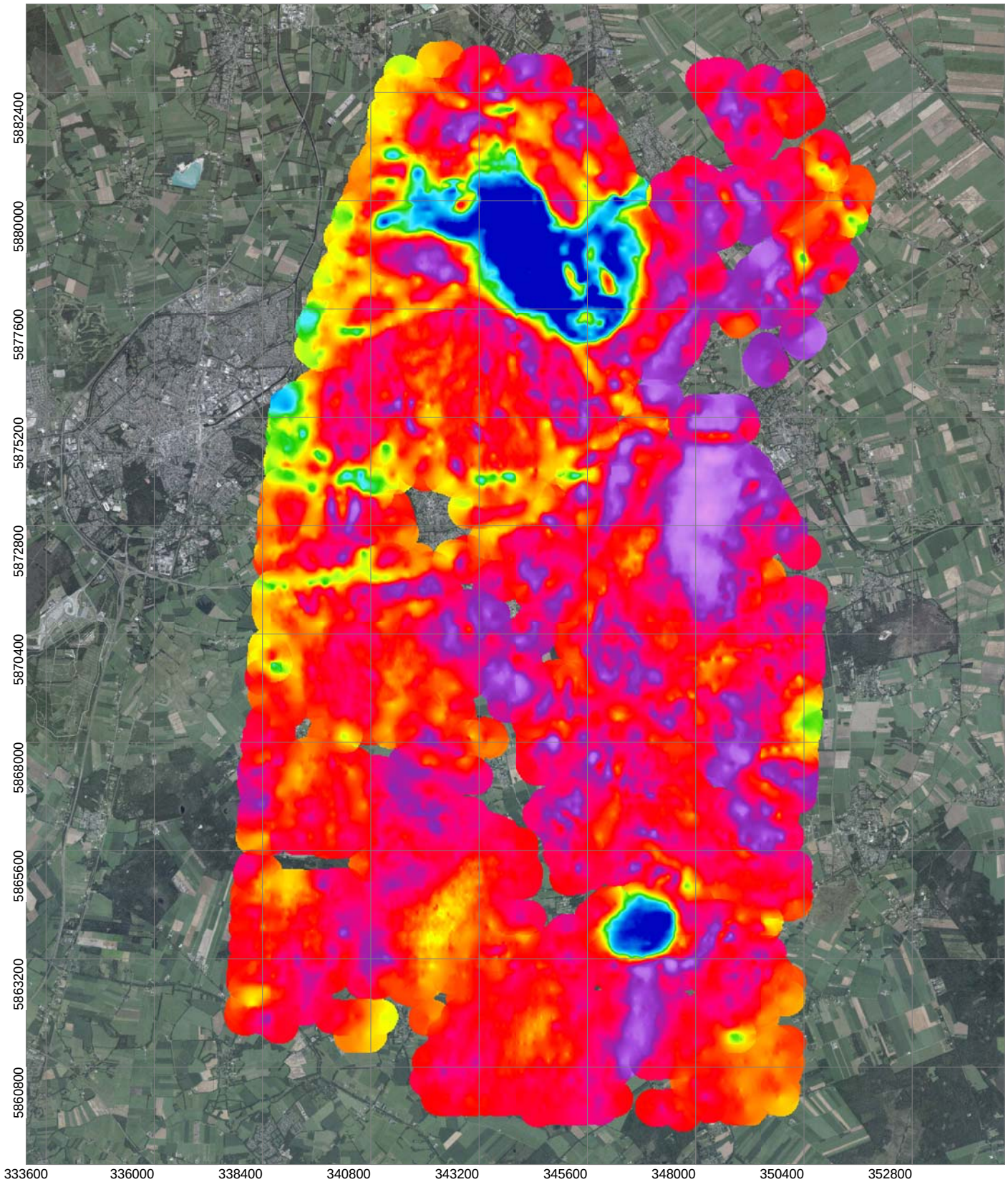
Mean Resistivity, Depth 100-110 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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Mean Resistivity, Depth 110-120 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000

Resistivity [Ohmm]

UTM 32N WGS84

5 km

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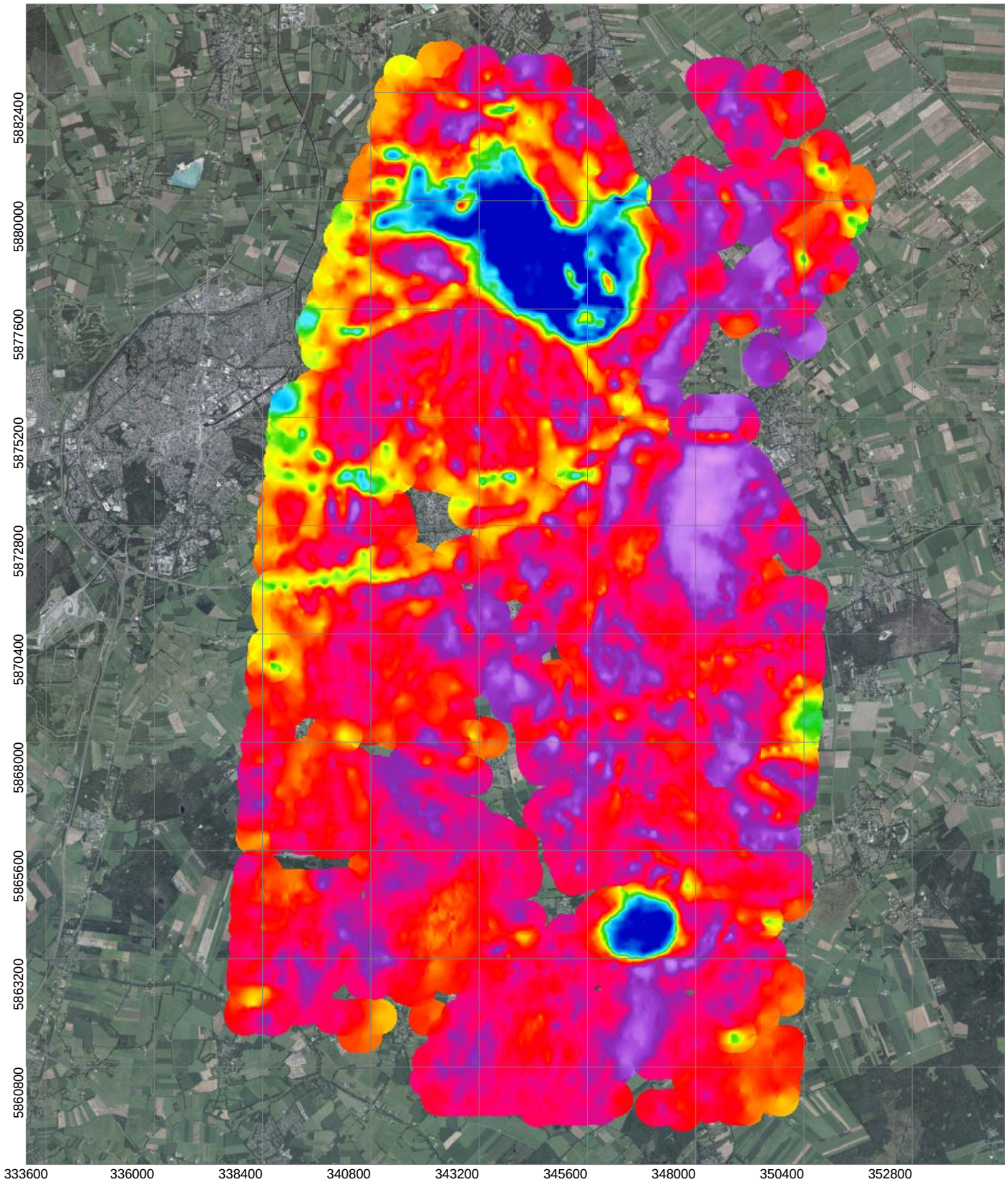

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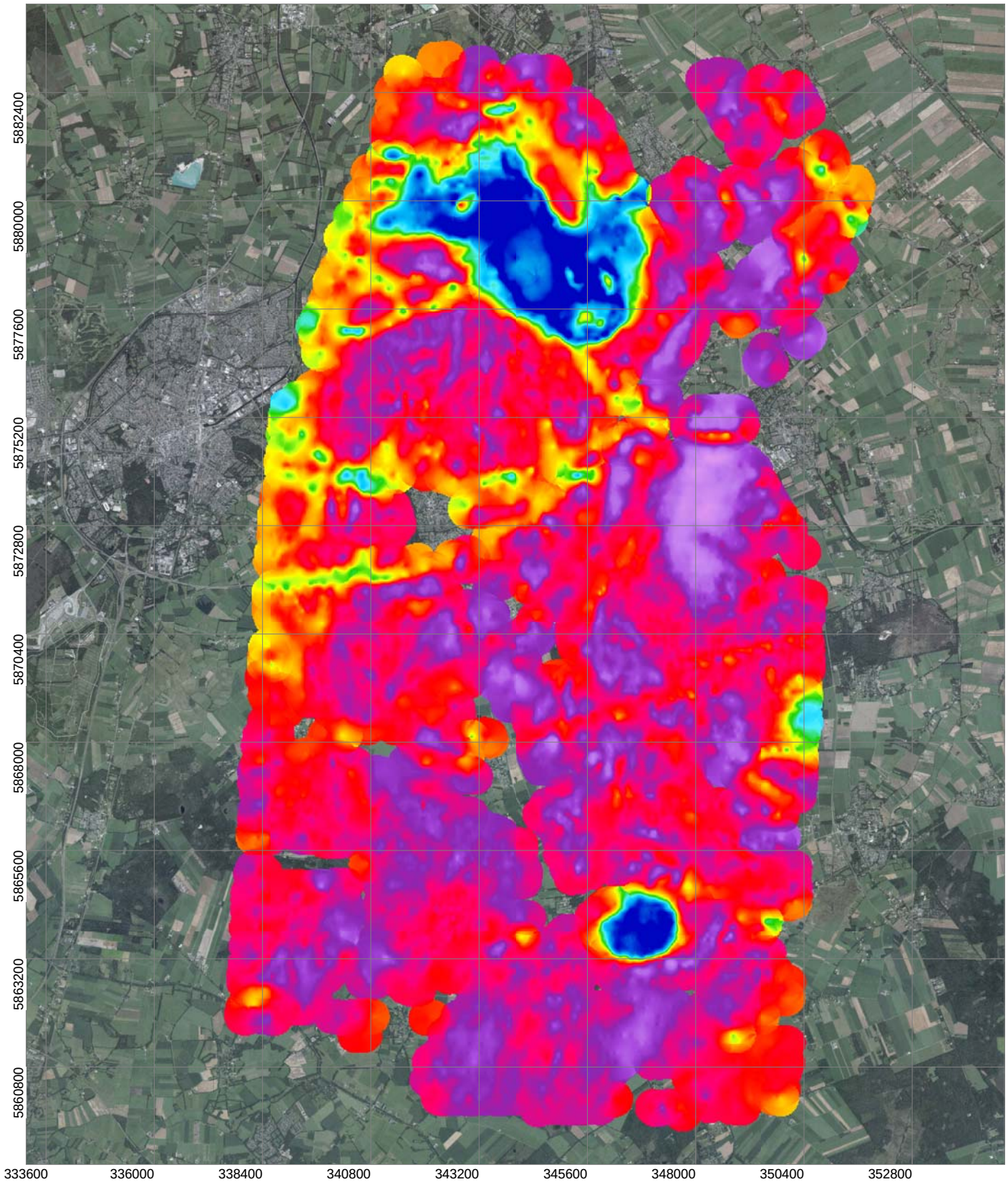
10 — 100 — 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 120-130 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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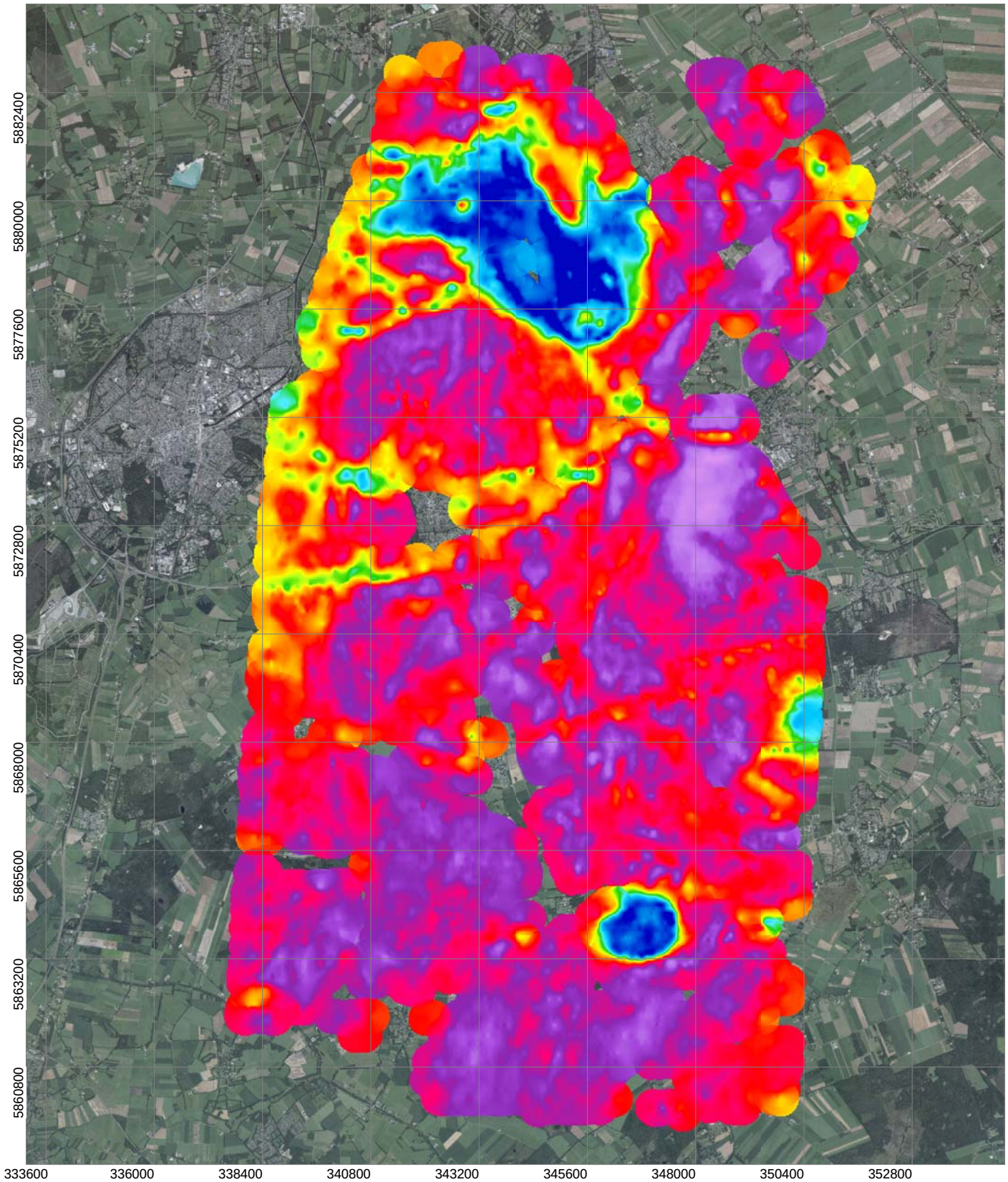
Mean Resistivity, Depth 130-140 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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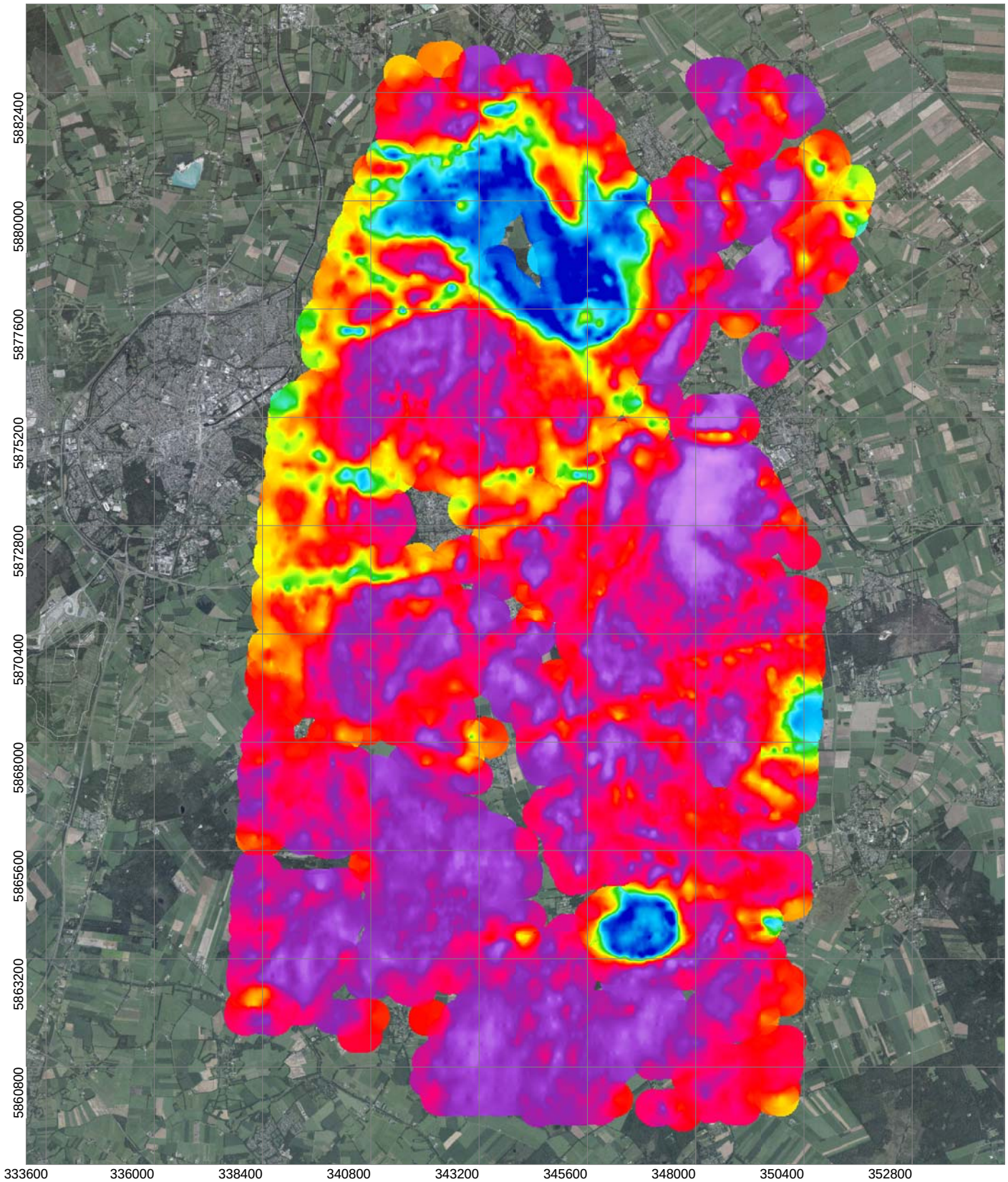
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 140-150 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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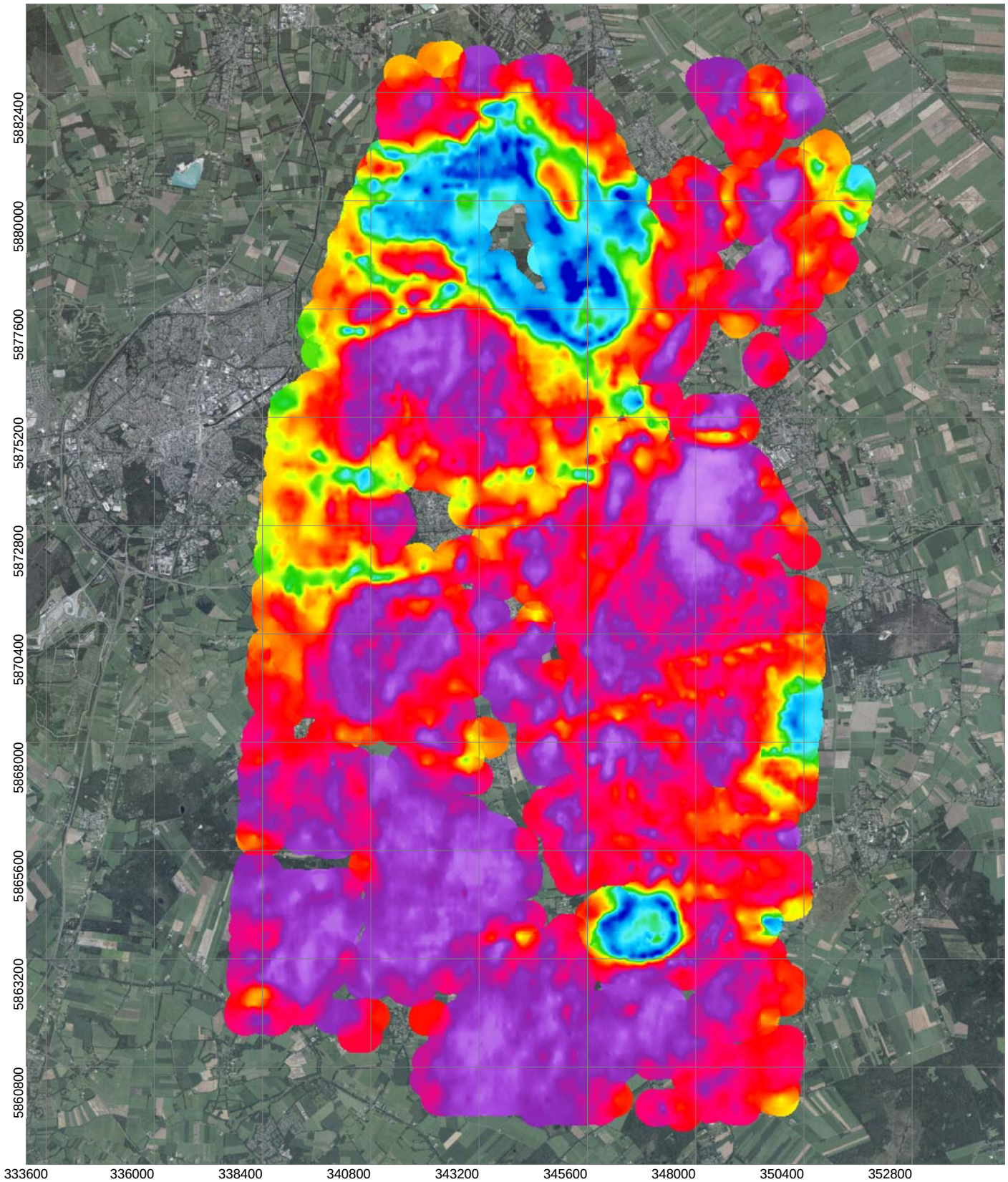
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 150-160 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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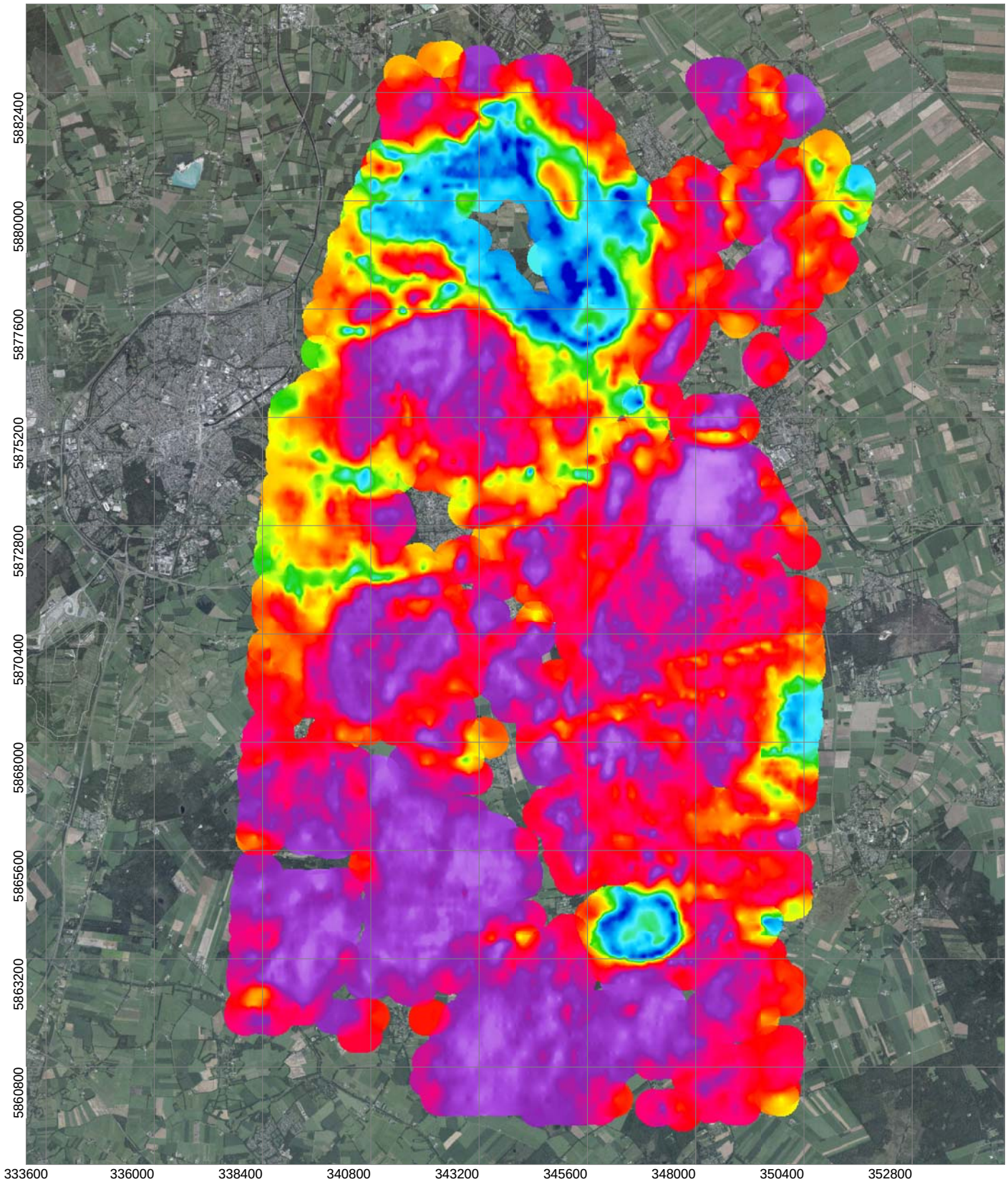
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 160-170 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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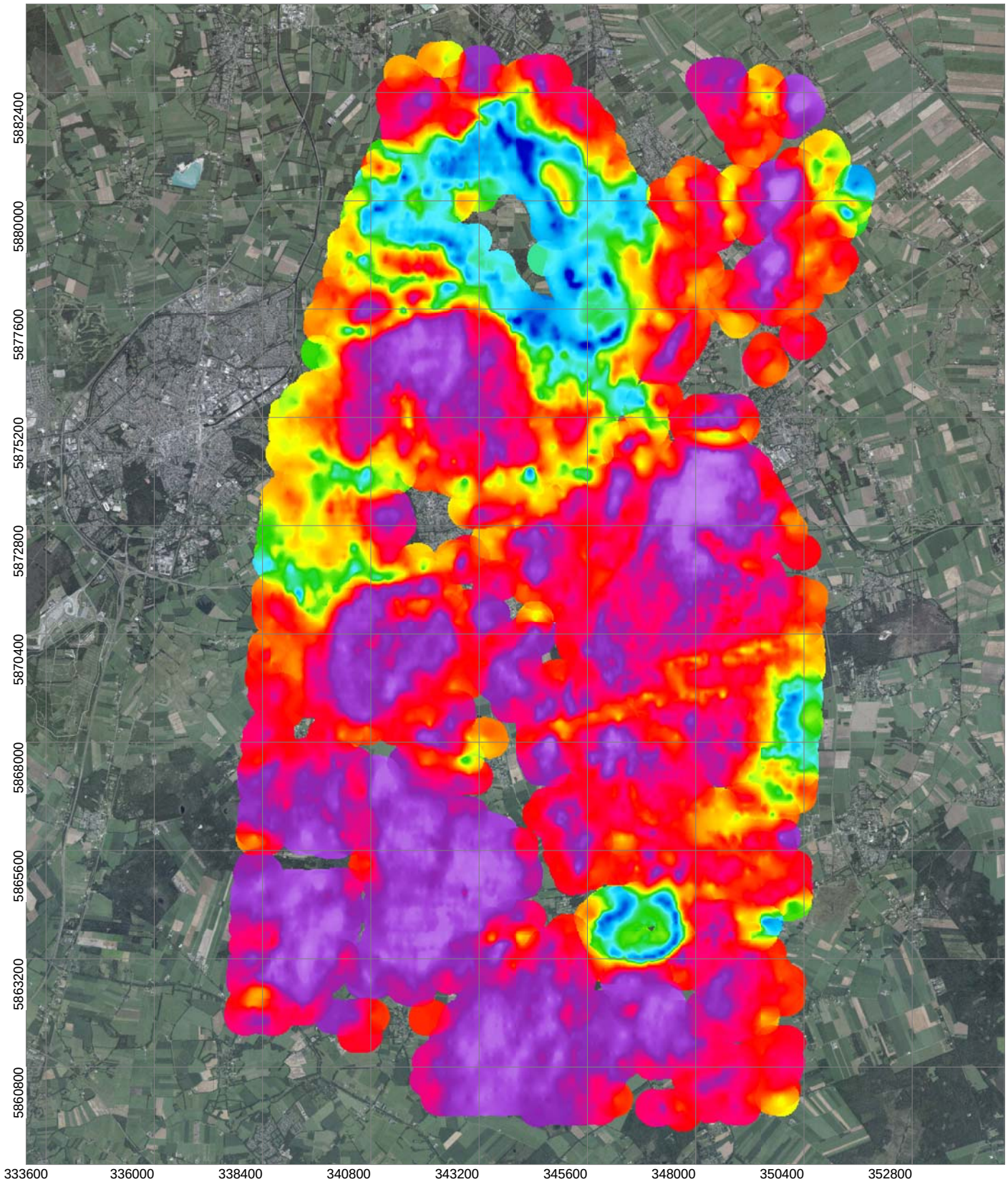
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 170-180 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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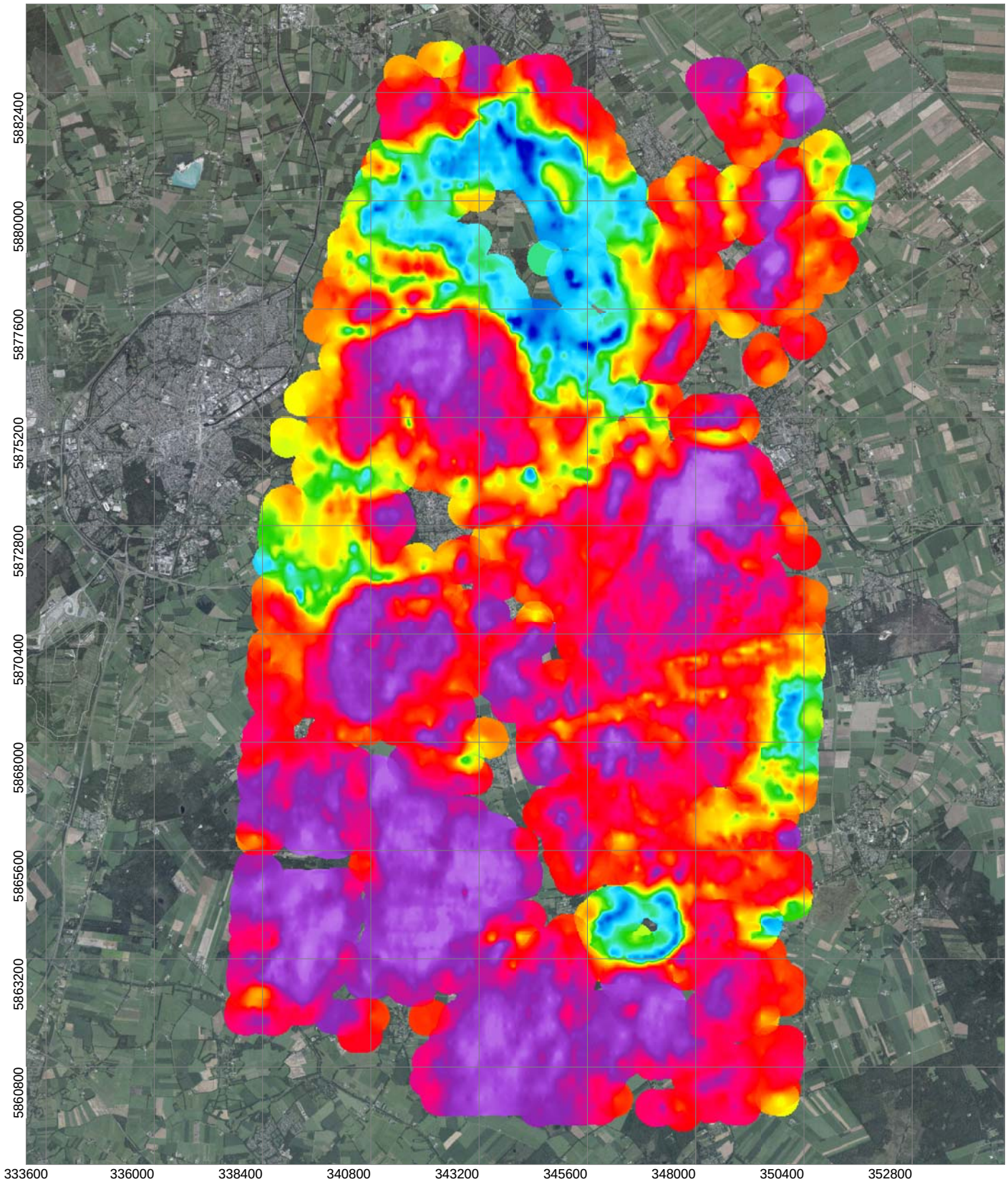
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 180-190 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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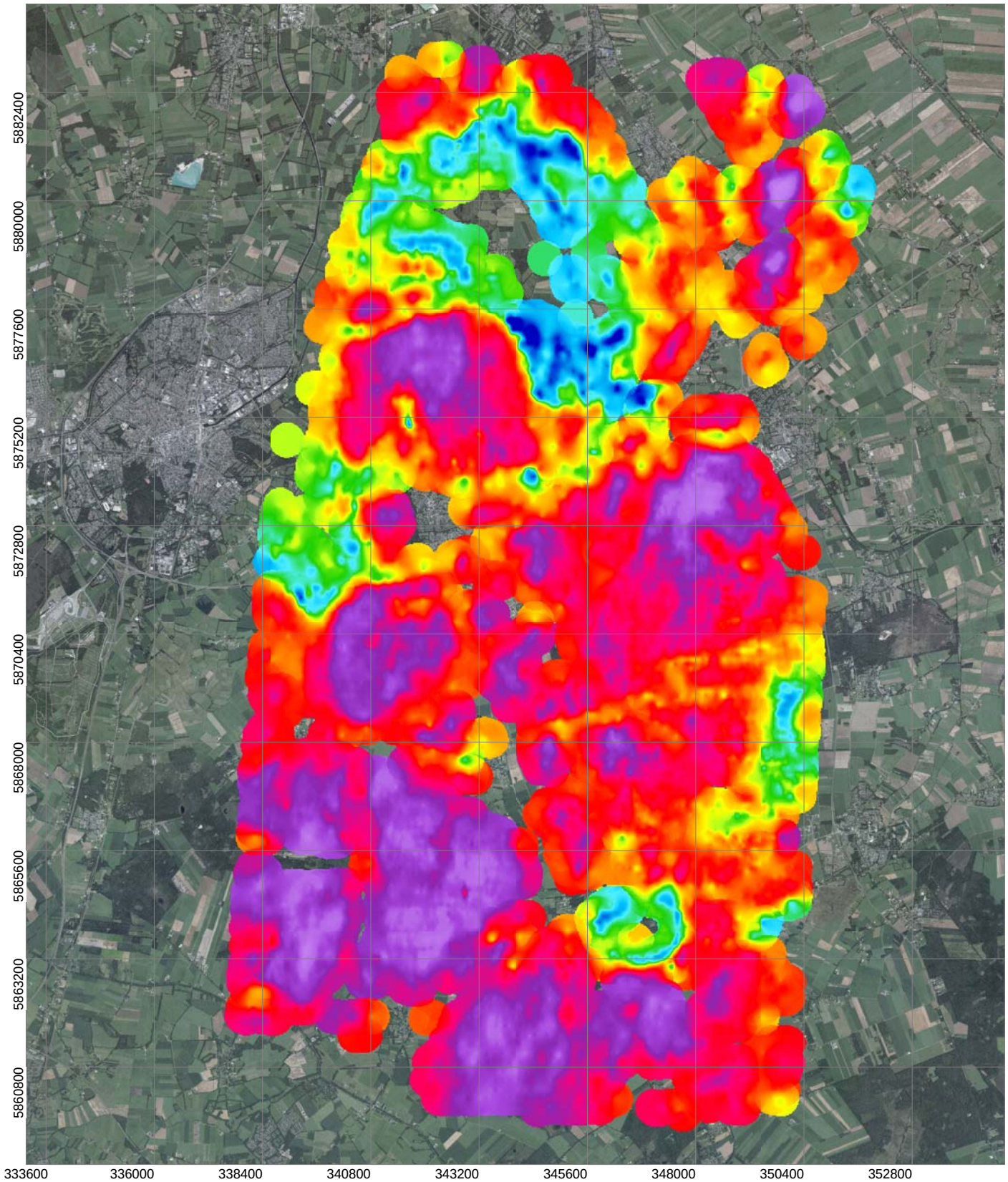
Mean Resistivity, Depth 190-200 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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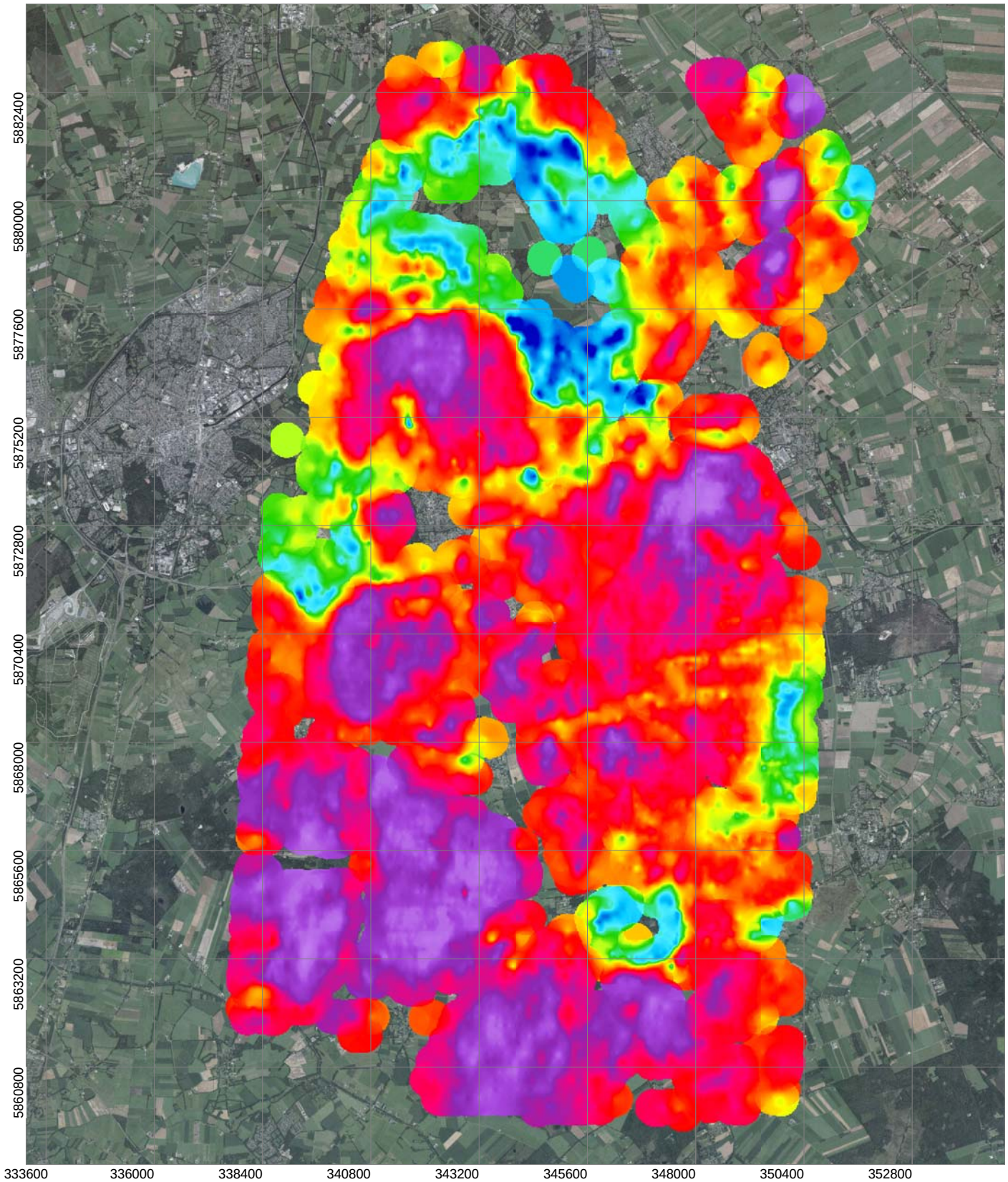
10 — 100 — 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 200-210 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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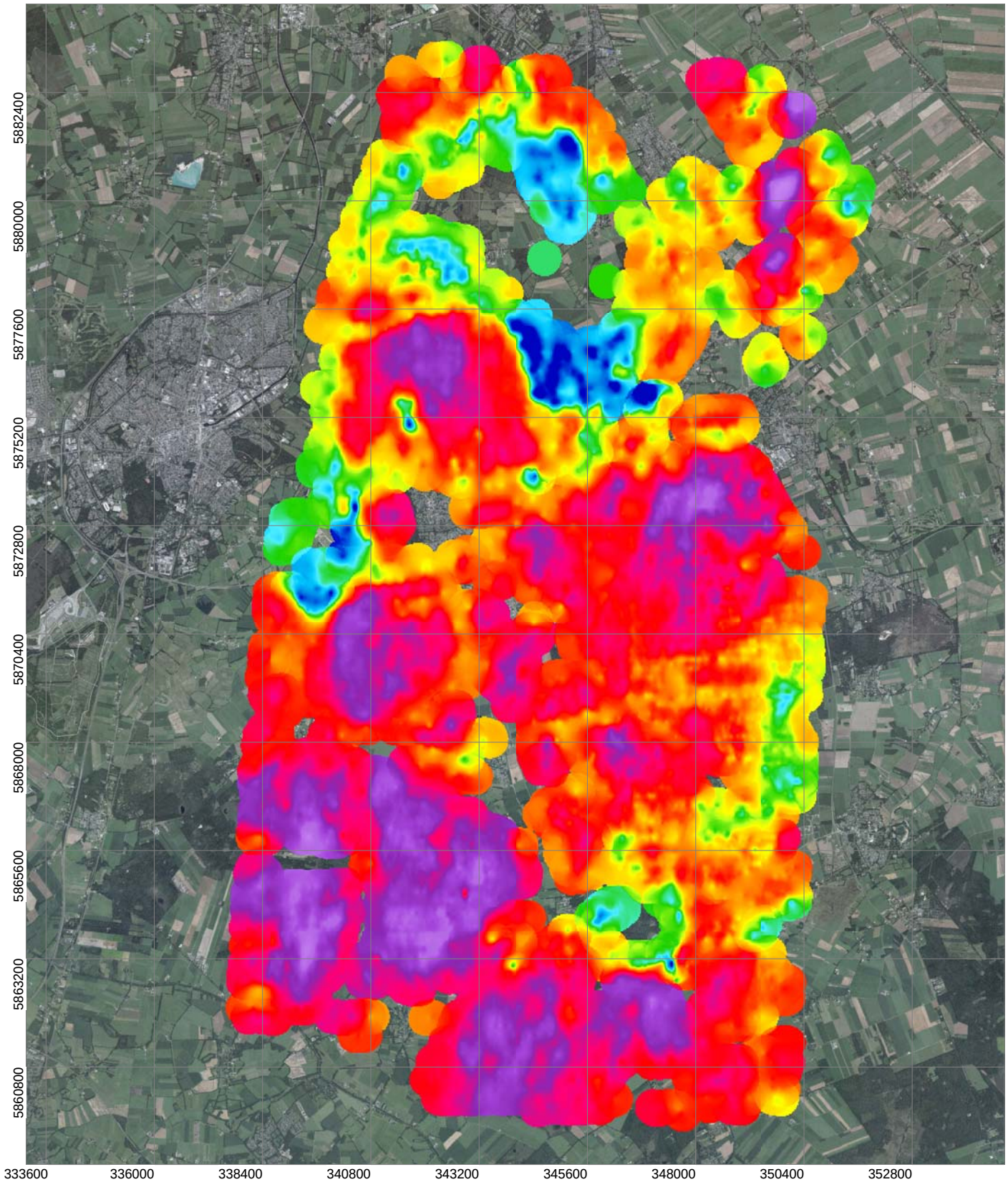
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 210-220 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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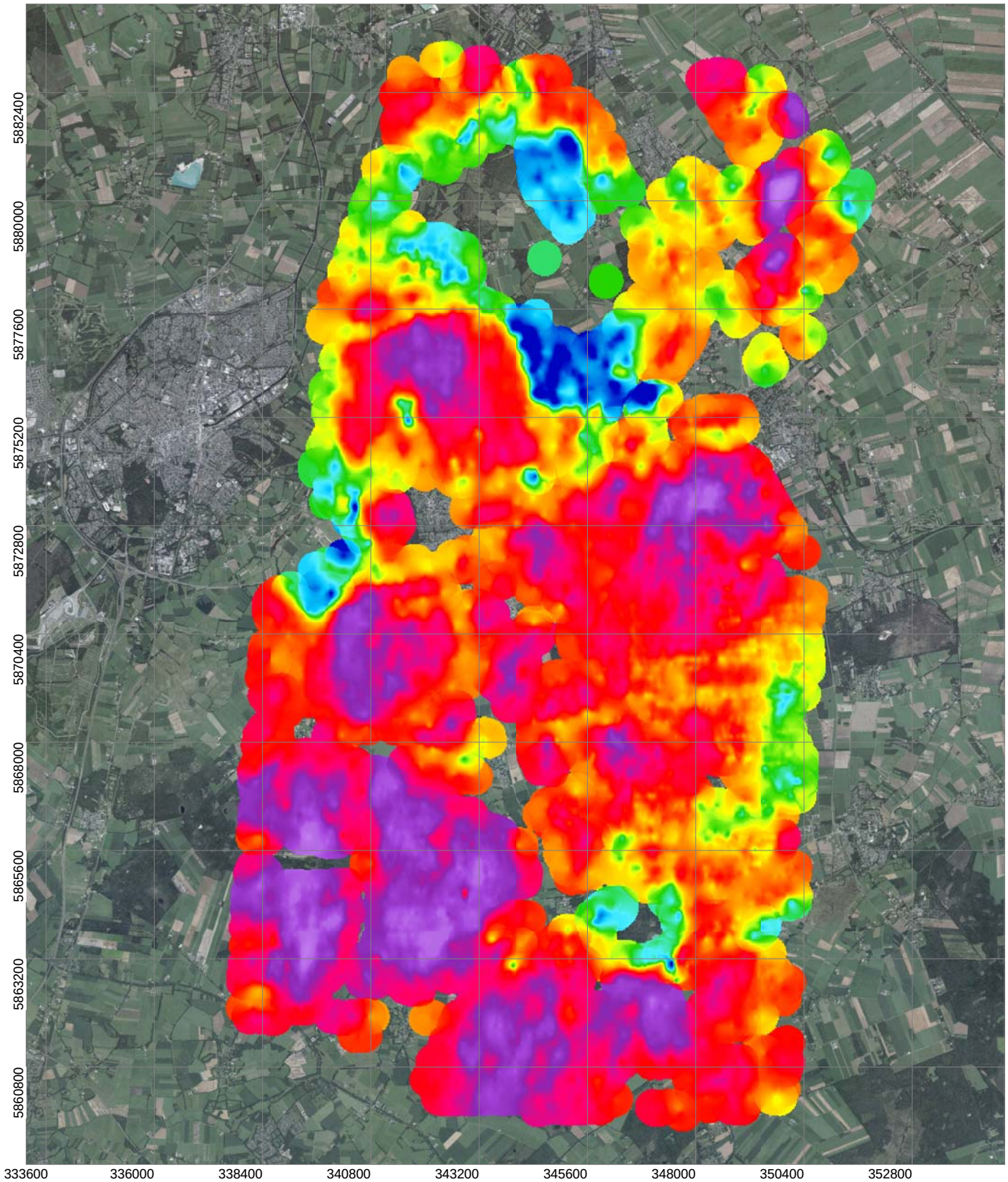
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 220-230 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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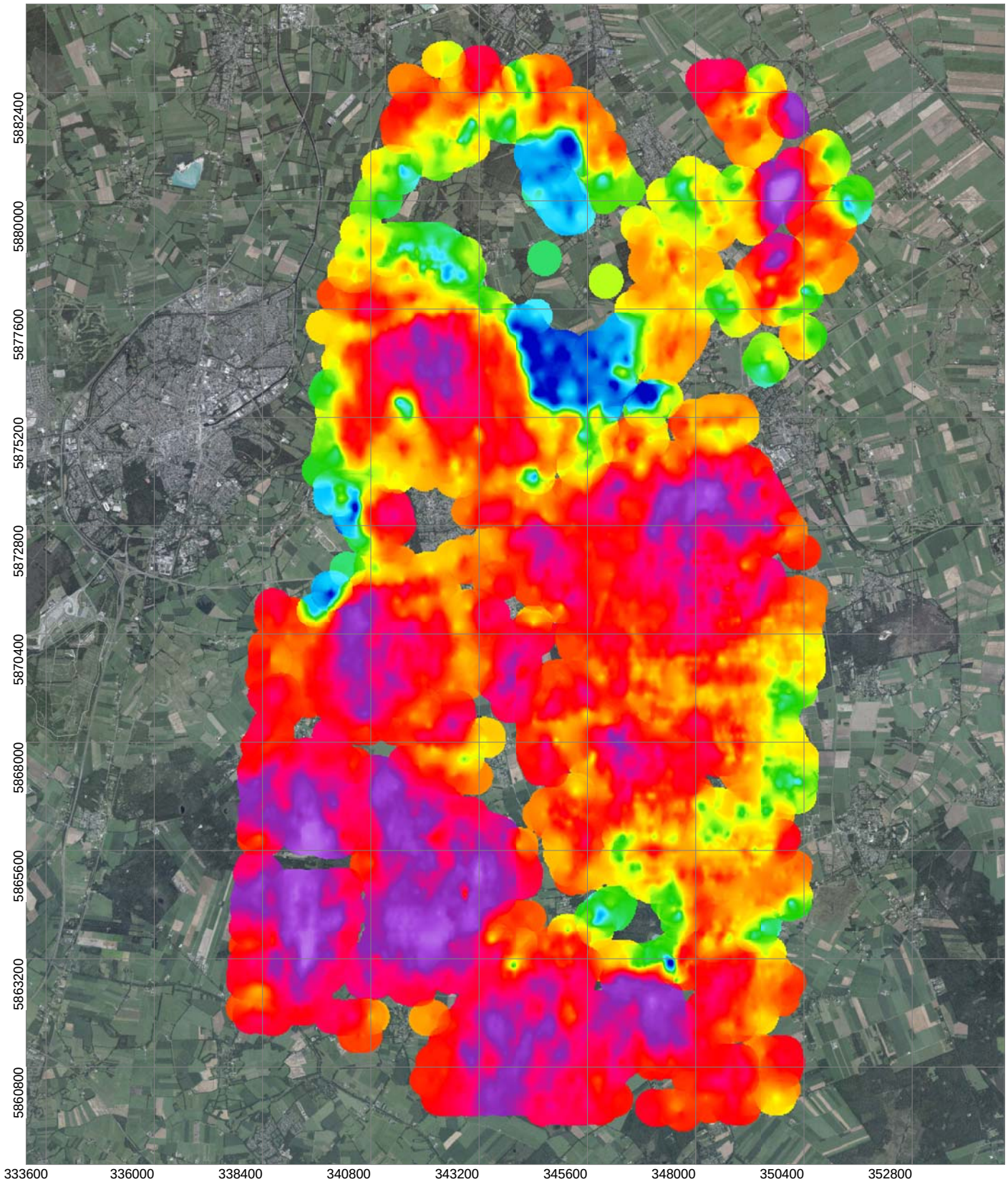
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 230-240 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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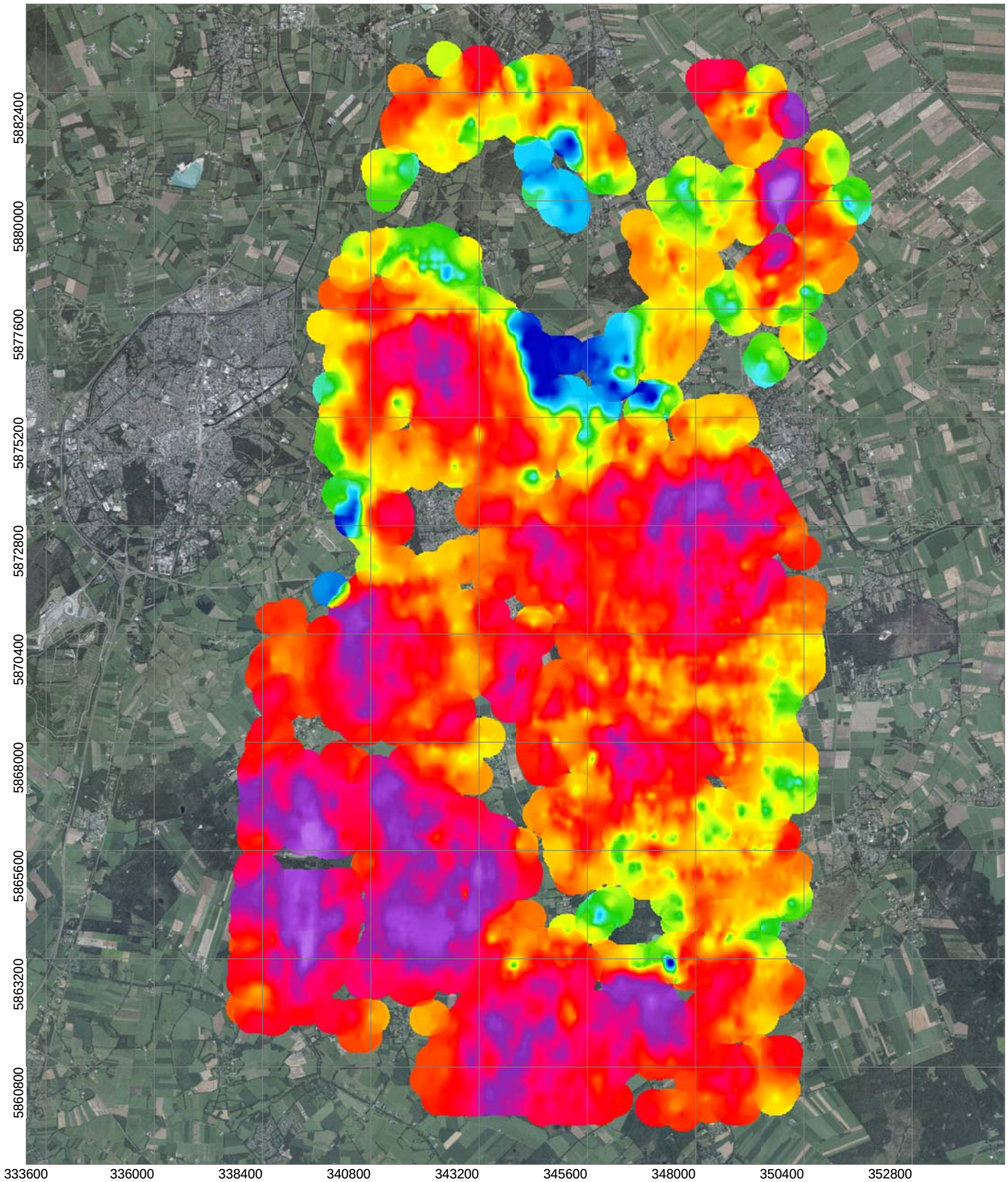
Mean Resistivity, Depth 240-250 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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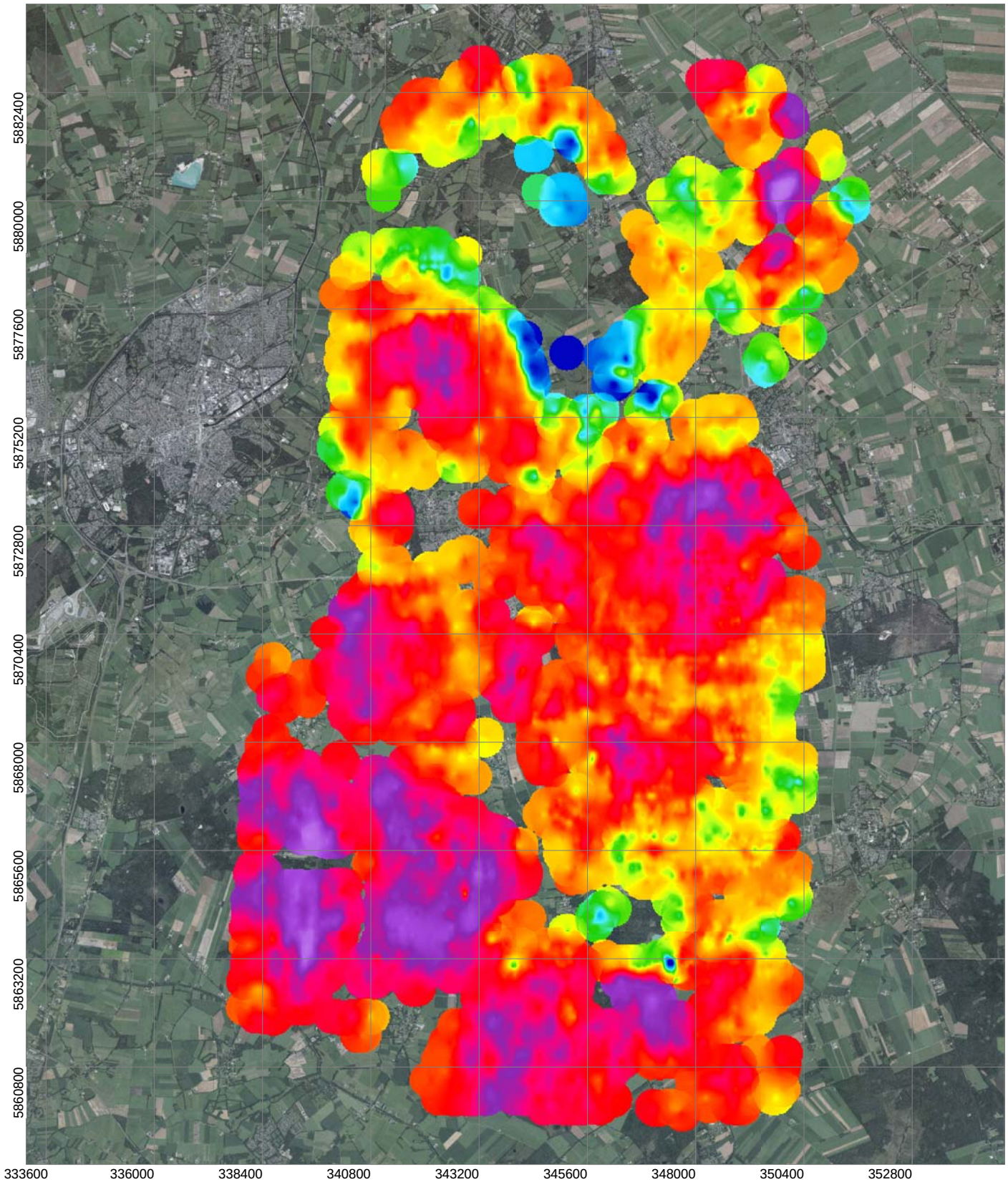
Mean Resistivity, Depth 250-260 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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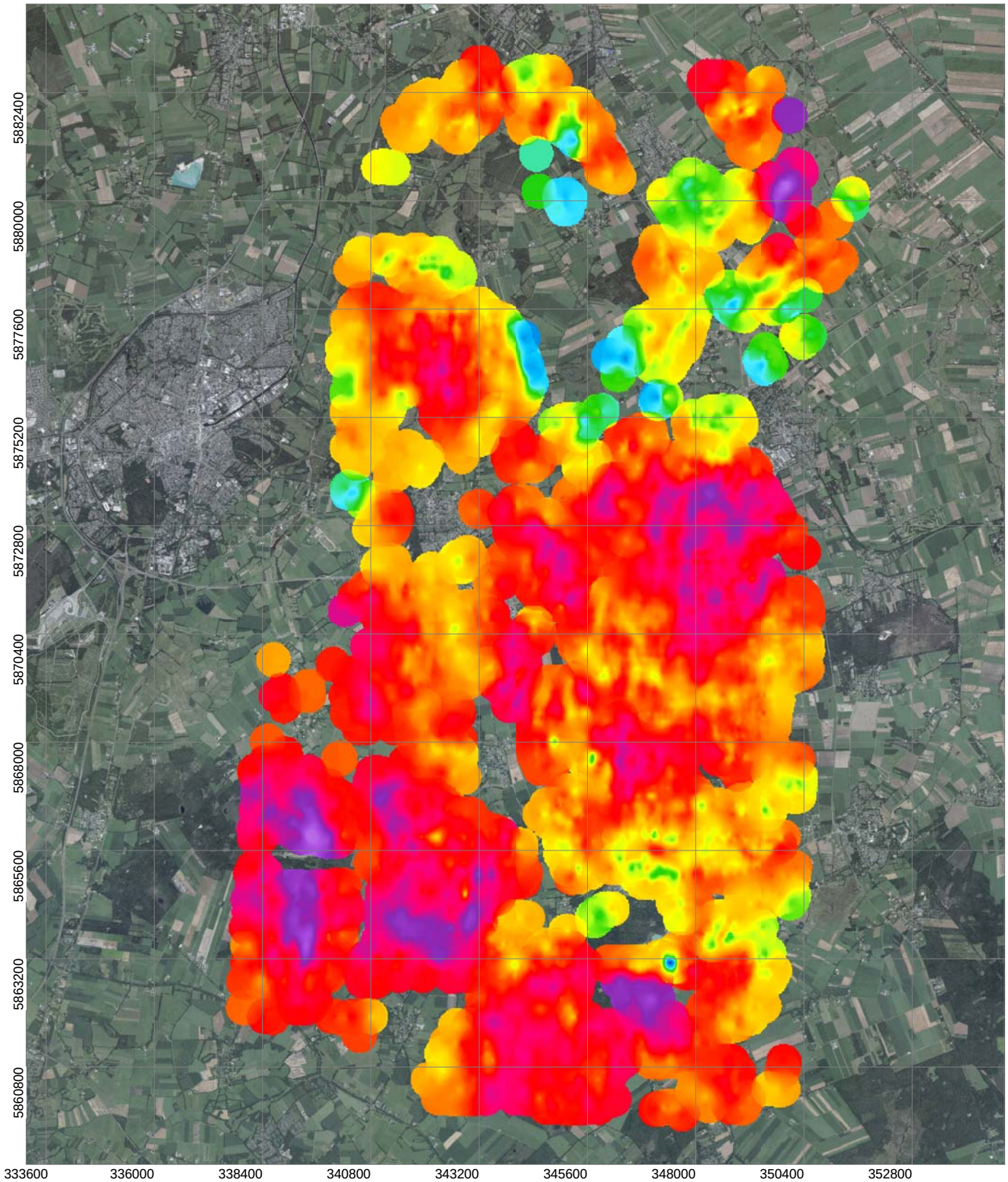
10 100 1,000
Resistivity [Ohmm]

Mean Resistivity, Depth 260-270 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

UTM 32N WGS84

5 km



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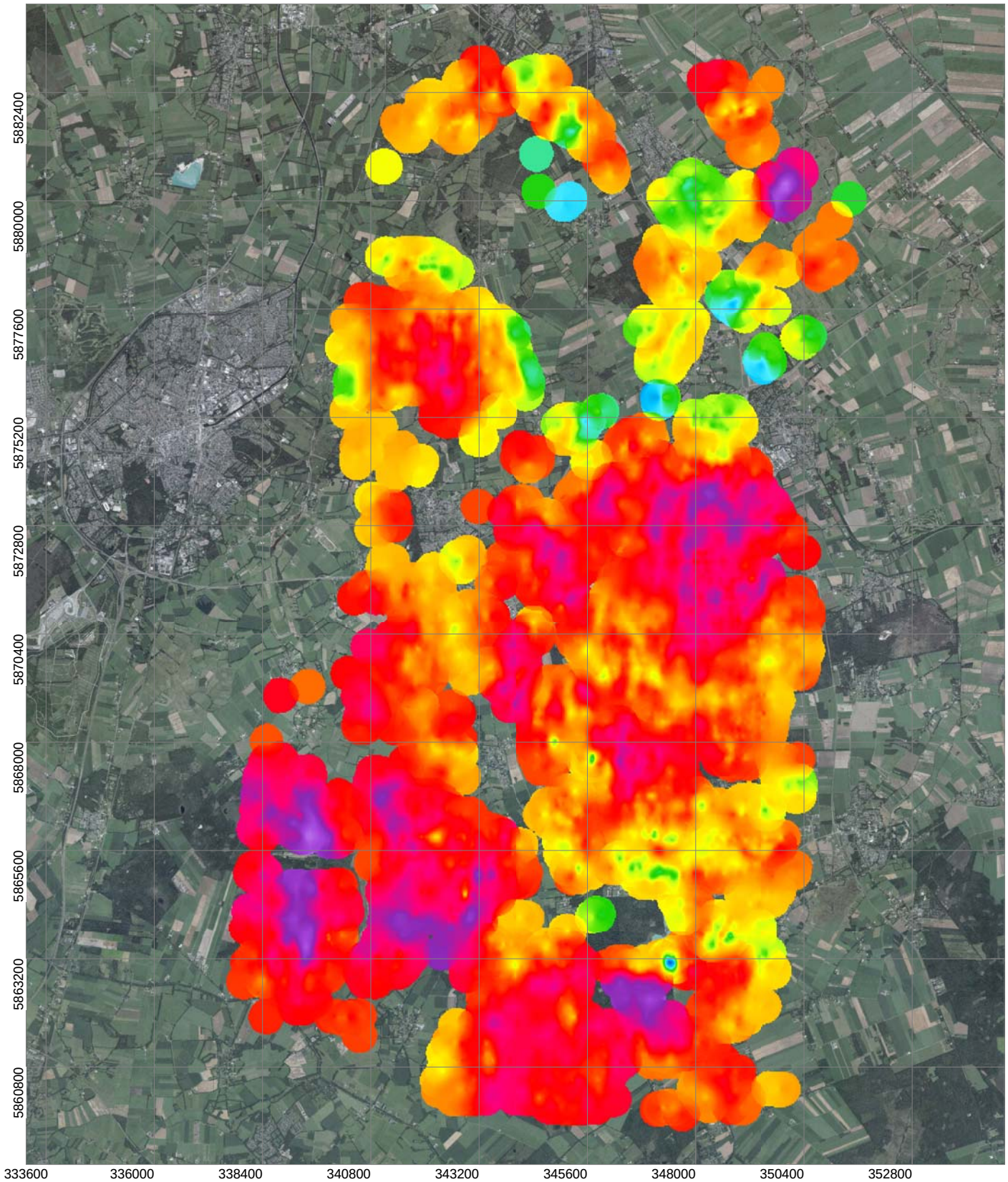
Mean Resistivity, Depth 270-280 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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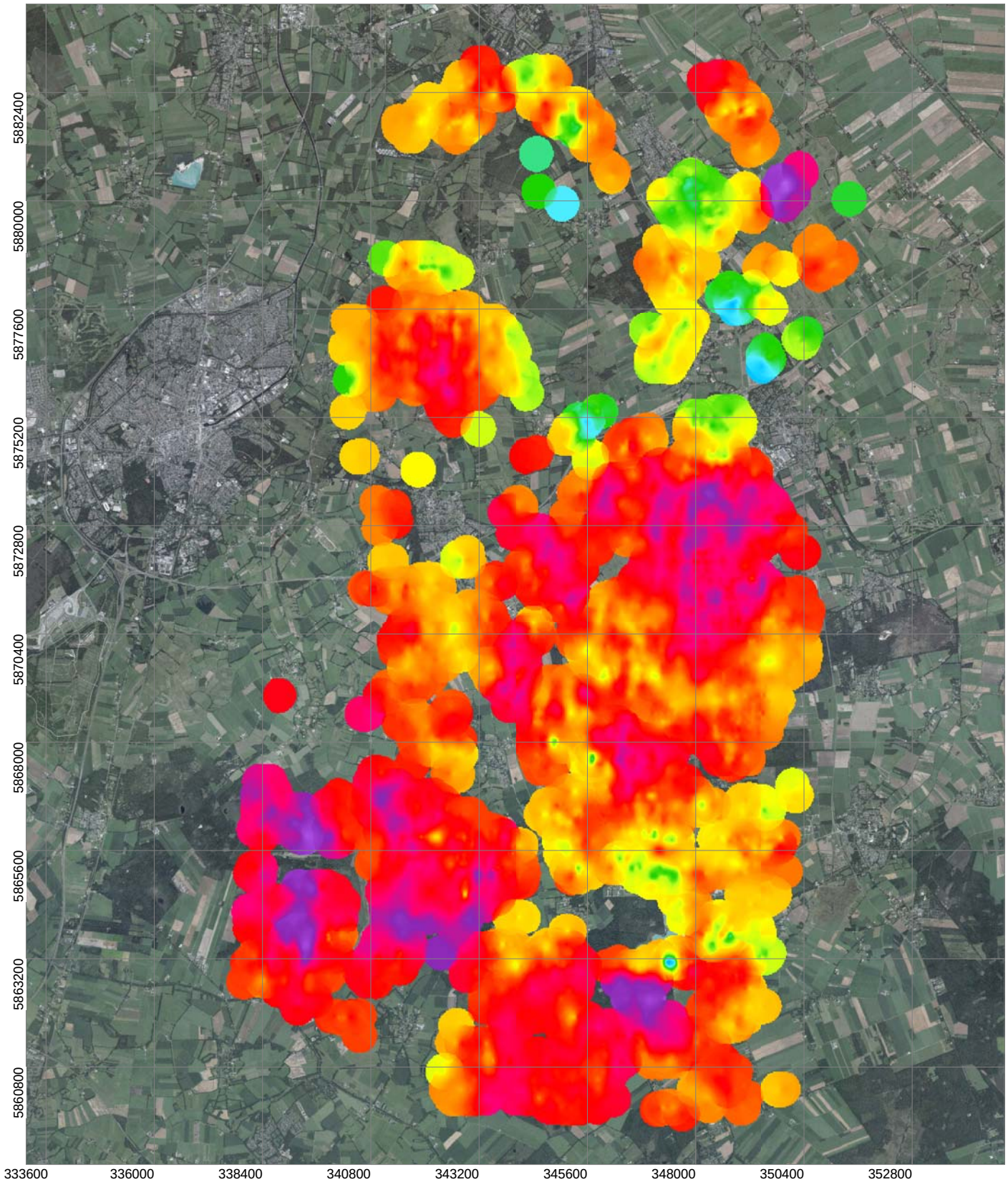
Mean Resistivity, Depth 280-290 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 100 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km



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Mean Resistivity, Depth 290-300 m (ohm-m)

SCI Smooth Model - Kriging, Search Radius 400 m

10 — 100 — 1,000
Resistivity [Ohmm]

UTM 32N WGS84

5 km