GEOSENSORS R6™
OPERATOR'S MANUAL

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Toronto

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FCC Regulatory Statements

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) This device may not cause harmful interference.

(2) This device must accept any interference received, including interference that may cause undesired operation.

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the Federal Communication Commission (FCC) rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment causes harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by doing one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

NOTE: THE GRANTEE IS NOT RESPONSIBLE FOR ANY CHANGES OR MODIFICATIONS NOT EXPRESSLY APPROVED BY THE PARTY RESPONSIBLE FOR COMPLIANCE. SUCH MODIFICATIONS COULD VOID THE USER'S AUTHORITY TO OPERATE THE EQUIPMENT.

RF Exposure Warning

This equipment complies with FCC radiation exposure limits set forth for an uncontrolled environment. In order to avoid the possibility of exceeding the FCC radio frequency exposure limits, human proximity to the antenna shall not be less than 20 cm during normal operation and must not be co-located or operating in conjunction with any other antenna or transmitter.

This equipment complies with FCC radiation exposure limits set forth for an uncontrolled environment. This transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

ISED Regulatory Statements

This device complies with ISED Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Le présent appareil est conforme avec ISED Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

CAN ICES-3 (B)/NMB-3(B)

RF Exposure Information

This equipment complies with ISED RSS-102 radiation exposure limits set forth for an uncontrolled environment. This transmitter must be installed to provide a separation distance of at least 20 cm from all persons and must not be co-located or operating in conjunction with any other antenna or transmitter.

Cet équipement est conforme avec ISED RSS-102 des limites d'exposition aux rayonnements définies pour un environnement non contrôlé. Cet émetteur doit être installé à au moins 20 cm de toute personne et ne doit pas être colocalisé ou fonctionner en association avec une autre antenne ou émetteur.

This equipment complies with ISED RSS-102 radiation exposure limits set forth for an uncontrolled environment. This transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

Cet équipement est conforme avec ISED RSS-102 des limites d'exposition aux rayonnements définies pour un environnement non contrôlé. Cet émetteur ne doit pas être colocalisé ou fonctionner en association avec une autre antenne ou émetteur.

EU Regulatory Statements

Geosensors Inc.

66 Mann Ave, Toronto, Ontario M4S2Y3, Canada

Hereby, Geosensors Inc. declares that this Ground Conductivity Meter is in compliance with the essential requirements and other relevant provisions of Directive 2014/53/EU. The declaration of conformity may be consulted at www.geosensors.com/eu/r_series_doc_2021.pdf

This product has been so constructed that the product complies with the requirement of with Article 10(2) as it can be operated in at least one Member State as examined and the product is compliant with Article 10(10) as it has no restrictions on putting into service in all EU member states.

Radiation exposure statement

This equipment should be operated with minimum distance of 20 cm between the antenna of this device and all nearby persons. This transmitter must not be co-located or operated in conjunction with any other antenna or transmitter.

Technical Specification

Model	GSIGCM R6
Transmitter	Single fixed frequency, five variants: A. 8400 Hz B. 8700 Hz C. 9000 Hz D. 9300 Hz E. 9600 Hz Consult product label for specific frequency
Transmitter Power	Max 125.1 dBuV/m at 3m for all frequency variants
Receivers	6 receivers coplanar with transmitter
Transmitter-receiver separations	0.5, 0.7, 0.9, 1.1, 1.5 and 1.95m
Power	12-28 VDC at 0.6 A
Total weight	7 kg
Size	2.41 x 0.89 x 0.89 (L x W x H in m)
Temperature (operating)	-30 to +40ºC
Temperature (storage)	-40 to +60ºC
Altitude	0-2000m
Humidity (operating, cable attached)	0-100%
Humidity (storage)	0-60%
Intended use environment	Outdoor

Important Information and Sample Label

SAFETY NOTE:

The R6™ should never be used in situations where its operation is safety-critical.

Like all ground conductivity meters, the R6™ uses a low-intensity EM transmitter operating at audio frequencies (approximately 9kHz for the R6™), to perform its measurements: it should not be used in situations where its transmitted field will cause interference with safety-critical systems or medical devices.

The internal GPS/GNSS receiver (when present) is used for timing and approximate positioning. Its location inside the sensor is not optimal for precise positioning of the sensor. Outputs from this device should never be used for navigation or safety-critical tasks.

The R6™ is a complex geophysical system. A great deal of time and effort has been invested to ensure that it is accurately calibrated, rugged and operationally stable. However, any geophysical tool should be tested frequently when being used for operations where instrumental accuracy and stability is vital. This can be done through routine repeat measurements at one or more "check sites" in the survey area or near the operating base. R6™ system stability should be maximized for nominal survey conditions after completion of its internal warm-up, and in particular for stable ambient temperature conditions with minimal temperature “forcing” by direct sunlight, wind or rain. As with all ground conductivity meters, ambient temperature variations will generate a small degree of transient EM response error during and immediately after the temperature change. Users who require a high degree of sensor stability should consider mounting the sensor in an insulated housing to reduce the impact of ambient temperature variations on output data.

PROPRIETARY INFORMATION:

Every effort has been made to ensure that the material included in this reference is accurate and current. If an error is noted, please contact Geosensors immediately so that the error may be rectified. Contact information for Geosensors is provided in Appendix C.

SAMPLE LABEL

This label and the Geosensors logo are trademarks of Geosensors Inc. They may not be used without the express written permission of Geosensors Inc.

GEOSENSORS R6™

OPERATOR'S MANUAL

1 Overview

This Operator's Manual provides the information required to assemble and operate the Geosensors R6™ Ground Conductivity Meter.

This manual is organised into the following sections:

1. Overview
2. What's in the package?
3. Cabling and power supplies
4. Operating the R6™
5. Streaming Data
6. Troubleshooting Guide

1.1 Intended Use:

The Geosensors R6™ Ground Conductivity Meter is intended for the measurement of near-surface apparent soil conductivity ECa and apparent magnetic susceptibility MSa[1]. The R6™is also capable of detecting the presence of some shallow conductive or magnetically susceptible objects beneath the soil surface, but this is not a typical operational objective for most users: most users of ground conductivity meters seek to estimate the variation of soil conductivity over a survey area for a range of depths.

1.2 Description:

The Geosensors R6™ Ground Conductivity Meter is a lightweight, battery-powered sensor for acquisition of multi-separation electromagnetic survey data. The sensor unit comprises a compact, stable, fully digital six-receiver "Slingram" EM sensor operating at specific frequencies in the vicinity of 9 kHz. It utilizes an M12 4-conductor cable for power and serial communications. The R6™ includes the following subsystems: an internal GNSS receiver, an internal sensor orientation monitor with 3D magnetic

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[1] "Apparent Conductivity" and "Apparent Magnetic Susceptibility", denoted here as ECa and MSa but often referred to as ρ_a and κ_a in the geophysical literature, are estimates of the electrical conductivity and volume magnetic susceptibility, typically obtained by electromagnetic sensors like the R6™. These sensors are normally operated above the ground surface, in contrast to direct or in-situ measurements of these quantities of samples of soil by laboratory instruments or by sensors embedded in the soil layer. "Apparent" indicates that the measurement is affected by sensor height above the surface, and typically includes the effect of more than one distinct soil horizon or earth material, *eg* a layer over an underlying halfspace. An easy way to visualize ECa and MSa is that sensor measurements of these quantities would be equal to the true soil conductivity and magnetic susceptibility when the sensor is lying on the surface of a thick (effectively infinite) layer having those true conductivity and magnetic susceptibility properties. If the sensor is lifted above the surface, measured ECa and MSa become smaller due to the presence of an "air layer" between the sensor and the soil surface. Also, since real soil properties typically vary with depth, ECa and MSa become weighted averages with respect to depth below the sensor of those soil properties.

compass capability, and a Wifi/Bluetooth module for communication with external computers and Android devices. The sensor uses an NMEA-style output mode in which sensor data are output to an external computer or data logger for display and recording, and it is equipped but not presently enabled to log data internally for subsequent download and analysis, to output data via the Wifi/Bluetooth module, or to output data from the magnetic 3D compass. The R6™ package is sealed, weatherproof, and contains no user-serviceable parts. The system is factory-calibrated, with low geophysical noise and drift levels. The sensor's data output sentences are described in Appendix A.

For more detailed description of specific system attributes, see the specifications table in Appendix B.

Each R6™ sensor is provided with one M12 four-conductor 5m "extension" (one male and one female connector) cable suitable for connecting to an M12 "sensor panel". Alternatively, a breakout cable can be supplied that provides a connection to a 12V battery and a serial communications adapter.

1.3 Basis of Operation:

The R6™ ground conductivity meter is a geophysical sensor comprising a six-receiver electromagnetic induction sensor for measurement of near-surface apparent soil conductivity ECa and apparent magnetic susceptibility MSa[2]. The R6™is also capable of detecting the presence of conductive or magnetic objects beneath the soil surface, but this is not a typical operational objective for most users and will not be discussed here. Most users of ground conductivity meters seek to estimate the variation of soil conductivity over a survey area for a range of depths.

During sensor operation, an oscillating transmitted electromagnetic field generated by the sensor's transmitter coil induces electromagnetic eddy currents in nearby conductive materials (typically, this would be the soil layer near the earth's surface.) These eddy currents are in turn detected by the sensor's receivers, which are coplanar with the transmitter and located at six distances from the transmitter. The distribution of the induced eddy currents with depth in the subsurface generates patterns of response in the receivers that can be used to estimate the depths of conductive or magnetically susceptible layers within the subsurface. In normal soils having moderate to low electrical conductivity, the eddy current distribution with depth is not strongly affected by the conductivity of the soil and makes a geometrically-derived depth of exploration a

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[2] "Apparent Conductivity" and "Apparent Magnetic Susceptibility", denoted here as ECa and MSa but often referred to as ρ_a and κ_a in the geophysical literature, are estimates of the electrical conductivity and volume magnetic susceptibility, typically obtained by electromagnetic sensors like the R6™. These sensors are normally operated above the ground surface, in contrast to direct or in-situ measurements of these quantities of samples of soil by laboratory instruments or by sensors embedded in the soil layer. "Apparent" indicates that the measurement is affected by sensor height above the surface, and typically includes the effect of more than one distinct soil horizon or earth material, *eg* a layer over an underlying halfspace. An easy way to visualize ECa and MSa is that sensor measurements of these quantities would be equal to the true soil conductivity and magnetic susceptibility when the sensor is lying on the surface of a thick (effectively infinite) layer having those true conductivity and magnetic susceptibility properties. If the sensor is lifted above the surface, measured ECa and MSa become smaller due to the presence of an "air layer" between the sensor and the soil surface. Also, since real soil properties typically vary with depth, ECa and MSa become weighted averages with respect to depth below the sensor of those soil properties.

good approximation. This condition is known as the “low induction number” or “LIN” approximation[3]. In highly conductive earth materials like seawater or marine clays, this approximation becomes progressively less valid at higher conductivities, because the induced eddy currents become concentrated near the surface and therefore do not sample as much at larger depths. Quantitative analysis of GCM surveys is typically performed by computer “inversion” software, which is beyond the scope of this document. The output of such quantitative analysis is often displayed as a set of maps or map layers corresponding to a series of depths. Sometimes the depth to a particular soil layer is displayed instead.

In general terms, EM responses that are only visible in the shorter transmitter-receiver (Tx-Rx) separation receivers of a multi-receiver system like the R6™ typically relate to shallow features in the subsurface, while EM responses that are not visible in the short-separation data but that become visible in the output of the longest Tx-Rx separation receivers relate to features at depths below the sensor comparable in length to the longest Tx-Rx separations. A useful way to think about this is that the volume of earth materials to which a given Tx-Rx separation is most sensitive increases with the Tx-Rx separation.

Under the LIN approximation, the nominal depth of exploration[4] in ECa for a given Tx-Rx separation and in the horizontal coplanar (sensor roll=0) configuration is typically defined as 1.5 times that separation. The corresponding depth of exploration in the vertical coplanar (sensor roll=90 deg) is 0.75 times the Tx-Rx separation. Note that these “depths of exploration” include sensor height as part of the depth, meaning that exploration depth within the subsurface is smaller by an amount equal to the sensor height. Since there are six Tx-Rx separations in the R6™ ranging from 0.5m to 2m, a range of detection depths can be explored simultaneously as the sensor is towed along a profile, permitting the user to approximately trace the depth to sufficiently contrasting conductive horizons over a range of 0.75m to 3m.

The R6™ sensor’s six coplanar transmitter-receiver separations are 0.5, 0.7, 0.9, 1.1, 1.5 and 1.95m. The instrument can be operated in the Horizontal Coplanar (transmitter axis vertical and Roll=0 degrees) or the Vertical Coplanar (transmitter axis horizontal, sideways to the sensor’s long axis, with Roll=90 or 180 degrees) orientations, or in a user-selected pitch-roll orientation relative to the ground surface. The sensor’s suite of six separations yields a 12-measurement electromagnetic sounding dataset (six ECa readings and six MSa readings) at each sample point, which is sufficient in many

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3 The LIN approximation as it relates to ground conductivity meters was discussed by Duncan McNeill in McNeill, J.D. 1980. “Electromagnetic terrain conductivity measurements at low induction numbers,” in Geonics Ltd. Technical Note TN-6. A more up-to-date discussion that also addresses magnetic susceptibility mapping was published by the ORBit group of Gent University in Hanssens et al, 2018 “Overcoming low induction number approximations: apparent electrical conductivity estimation for frequency domain electromagnetics and its potential for simultaneous magnetic susceptibility mapping,” in EGU2018 Proceedings, p 19714.

4 “Depth of Investigation” for a given Tx-Rx separation and sensor orientation under the LIN is conventionally defined as the depth at which the cumulative response reaches 70% of its total value. This is fairly well described in the McNeill TN-6 document referenced above, and has been discussed with applications in more detail in many other publications, *eg* Saey et al, 2008, “Comparing the EM38DD and Dualem-21S Sensors for Depth-to-Clay Mapping”, Soil Soc. Am J 73:7-12.

situations to resolve a layer of moderate thickness and conductivity or susceptibility over a deeper substratum of contrasting conductivity or susceptibility.

2 What's in the Package?

The R6™ can be purchased as a sensor for inclusion in user-provided sensor systems.

The R6™ sensor typically ships with a data cable in a tubular plastic shipping case or, optionally, a metal shipping case.

2.1 Installing the R6™ Unit:

Sensor clamps used to mount the sensor should be entirely non-metallic and non-conductive. It is acceptable (with the owner's approval!) to bond the unit in place using "peel-able" bonding agents such as some silicones in order to prevent sensor rotation in the clamps. It is important to secure the sensor against sensor rotation because sensor output varies within a factor of two depending on roll. The normal operating orientation is Horizontal Coplanar, with transmitter and receiver axes all pointing up, though the sensor can be used in Vertical Coplanar orientation (with transmitter and receiver axes pointing horizontal) if reduced depth of investigation is desired.

3 Cabling and Power Supplies

3.1 Data and Motorized Surveying Cables:

The system is normally provided with a Data Cable with a circular 4-conductor M12 connector at one end and a female D9 connector at the other. This cable can be used to control the instrument from a remote computer or log data into a remote computer during data acquisition. The Data Cable's grey power cable is supplied with a CLP (lighter plug) connector or "flying leads" if so ordered, which can be connected to a 5W 12VDC supply.

Alternatively, a 4m "extension" cable can be supplied, providing a circular male M12 plug at one end for attachment to the R6, and a female M12 jack at the other end for attachment to a suitable interface panel.

A "USB" cable is also available, which allows for direct connection to most computers that have a USB socket capable of providing 4W or more. This cable supplies both power and serial (via appropriate device driver) connections between the computer and the sensor. This cable is recommended due to its convenience for setup and testing, but not for routine surveying, where vibration will eventually damage the USB connector.

When the R6™ starts up, a data terminal connected for 115200 baud operation will display a stream of NMEA sentences.

4 Operating the R6™

4.1 Pre-survey considerations, precautions and checklist

While the R6™ is weatherproof when an IP67 M12 data cable is properly mated to the sensor's main connector, it is not immersion-proof, so avoid excessive exposure to water, particularly salty or fertilizer-contaminated water, as much as possible.

The instrument should be placed on the ground surface or in a nonmetallic sled or cart on the ground surface before surveying and allowed to come to ambient temperature. This will maximise instrument stability. Leaving the instrument powered up during this step will result in the best degree of stabilization.

The instrument should never be powered up while adjacent to highly conductive objects such as metal shipping cases, tool boxes, metallic boat hulls, metallic ship's decks and truck beds, concrete slabs with internal steel reinforcements, etc. Doing so will affect the instrument's calibration and will almost certainly result in non-recoverable data errors in data acquired during that power-up period. Powering down the sensor and restarting it on or above the ground surface, with no adjacent metal or other highly conductive materials in the immediate vicinity, will reset this condition and allow surveying to proceed.

Any logging/monitoring computer or tablet should be kept at least 0.5m and preferably considerably farther from the instrument during power-up and operation to minimize offsets due to the small but nonzero EM anomaly of these devices. The larger the tablet or computer is, the stronger its EM anomaly will be and the farther it should be kept from the sensor. An external GNSS unit should be mounted at least 1m and preferably more above the sensor to prevent sensing of the GNSS by the sensor. Even at this distance, it is likely that the sensor will sense the GNSS to some extent. Locating the GNSS mast above the transmitter's centre point (about 0.35 m or about 14 inches from the connector endcap) is convenient when the sensor is deployed on a sled.

The R6™ operates at a factory-selected frequency of 8400, 8700, 9000, 9300 or 9600 Hz to permit operation of the sensors in relatively close proximity (> 0.5m axis-to-axis separation). If two or more R6™ units configured with the <u>same operating frequency</u> are operated within a few hundred metres of each other, the transmitted field of one unit will interfere with the other unit(s) and vice versa, generating noise in the recorded data. Units with identical frequencies should therefore be operated with at least 200 metres minimum separation to minimize such interference.

Equipment Checklist:

1. R6™ instrument and sled or cart, towing rope
2. Data logging device
3. Spare battery pack, wrench for clamping bolts if sled or cart is used. Store any spare batteries in an inside pocket, wrapped in non-conductive material, and protect the terminals from short circuits
4. Battery chargers (if batteries are to be recharged using an AC generator while on-site, perhaps during a lunch break)

5. Computer for assessing any recorded data.
6. This reference

4.2 Power-on

The unit can be powered up by connecting sensor's logging or Data Cable to a suitable power supply. After a short period of self-calibration, the sensor will output a short series of self-identification packets, followed by a sequence of NMEA-type data sentences at an interval specified by the sensor's Output Data Rate. Typically only the processed EM and auxiliary data sentences are enabled for output. If the internal GNSS is active and its outputs are enabled, a variety of GNSS packets may also be output.

4.3 Survey methodology

General Considerations and Constraints

The R6™ is built to withstand reasonable levels of impact or vibration. However, like any complex device that includes precision structures and electronics, it should not be dropped onto hard surfaces, run over or into by vehicles, or rammed into rocks or tree stumps. The logger to sensor cable is somewhat vulnerable to damage, particularly from sharp edges or crushing and localized loads, and it does become stiffer and more vulnerable at extremely low temperatures. Many surveyors run this cable from their motorized tow vehicles to the sensor sled through a flexible conduit to protect the cable.

The R6™ has been carefully sealed and is generally weatherproof, but it is not immersion-proof—do not permit it to be submerged in water. If this does occur, disconnect power at once, rinse the exterior (with fresh water) and dry the affected components, in order to remove salts or fertilizers where present that may promote corrosion. Do not use compressed air or pressure washers to clean connectors or their vicinity, as this will damage the sensor's seals.

If the instrument is being towed by a vehicle, a special "extension" tow cable with serial communications wiring and internal power feed is a good choice, and the data logger can be plugged into this cable, with the logger's power plug being attached to the vehicle's power system or a set of batteries, taking care to ensure the correct polarity. The instrument's battery pack, if you use one, should not be used when external power is applied. External power applied through this cable can range in voltage from about 12V to 24VDC, but should not lie outside this range. The instrument will operate whenever its power is connected.

The tow cable should be attached with care to the tow bar, sled and to the tow vehicle as well, including service loops at all hinge points in order to avoid straining the cable or its connectors. An "expendable" M12 to M12 "extension cable" can be inserted at the service loop between the tow vehicle and tow bar if desired. This cable would be tightly attached to the tow bar and to the tow vehicle using multiple tie wraps/cable ties, so that if the hitch failed or popped off, the short extension cable would break or be damaged, rather than the more expensive tow cable. For attachment of the tow cable to the sled and tow bar at other locations, tie wraps are not ideal because if pulled tight, they can kink the conductors and could under some conditions cause localized fatigue and failure of the cable. Velcro wraps can be helpful in this situation. Use strain and compression relief wherever tie wraps may be desired, such as several wraps of tape around the cable, tapering to each side of the attachment point, to increase the minimum radius of curvature and avoid fatigue. Route the GNSS and EM cables to minimize bending and provide basic strain relief.

Running a Survey

The following are general guidelines and should not be considered to be complete instructions for performing surveys. A manual for good survey practice would be larger than this manual.

Maximising Positional Accuracy:

A good quality differential GNSS receiver and antenna system logged by the same data logger used for the R6 sensor(s) should be used to record positional information.   The sensor's internal GPS, if activated, is primarily included for timing purposes and is not accurate enough for detailed surveys.

All geophysical sensors and GNSS receivers require warmup before they yield their best data. For this reason, the complete survey system should be allowed to run for at least five minutes (and preferably 20-30 minutes) before starting to survey after a power-up. This would normally be the case in any event, since the EM sensor should be allowed to warm up for 20-30 minutes before surveying.

Since the EM sensor contains numerous receivers, the "plotting point" for each transmitter-receiver pair will occupy a different position relative to the transmitter (main connector) endcap: for the R6 these will be at 0.6030, 0.7030, 0.8030, 0.9030, 1.1030 and 1.3280m for the 0.5 through 1.95m separations.

If the GNSS antenna were located directly above the EM transmitter location-, then the plotting offsets from the GNSS position will be 0.2500, 0.3500, 0.4500, 0.5500, 0.7500 and 0.9750m.

> Note that placing the GNSS antenna or receiver directly above the transmitter is not an ideal location if the antenna and its ground plane are "visible" to the EM system, as when they move they will generate noise in the EM output. The user should determine the optimal location for their system and for their needs.

This plotting convention can be validated using a "lag test" in which the sensor is moved in two opposing directions over a shallow, long linear anomalous object lying on otherwise uniform ground and oriented at right angles to the survey direction, while recording data. The resulting anomalies of the anomalous object should be consistent within the accuracy of the GNSS receiver.

After startup, the R6 outputs data continuously until it is powered off. It is good practice when using a logger to "pause" data recording when performing turnarounds, adjusting the lateral position of the sled and so on, as this will minimize the chances of the EM sensor "seeing" conductive objects in the operator's backpack, boots etc, or the tow vehicle if one is used.

When the wheeled “cart” variant of a surveying sled is used, it may track slightly offline or shift laterally due to irregularities on the surface. This tendency is reduced when using ta sled on its own. If an assistant is available, a supplementary control rope can be manipulated by the assistant to help maintain the correct axial direction and tracking of the cart/sled. This can be especially helpful where the survey line is oriented perpendicularly to the slope of the ground.

Maximising Sensor Stability and Accuracy

Logging computers and their ancillary controls and battery packs contain conductive components. Even if a separate power supply is being used, placing the logging computer, interface device or an external battery within two metres of the transmitter or receiver coils of the sensor will generate offsets in the EM data that cannot easily be estimated and removed later. The transmitter is located on the sensor’s long axis centered close (0.353 m) to the connector endcap of the EM sensor, while the receivers are located at 0.5, 0.7, 0.9, 1.1, 1.5 and 1.95m from the Tx center. The rule of thumb is to keep ALL conductive and magnetic objects at least 0.5m and preferably farther away from the axis and ends of the instrument, and larger objects need to be kept further away than small ones. The internal GNSS has already been factored into the sensor’s calibration. Very small external GNSS units or antennas should be located on a stiff mast at least 1m and preferably 1.5m above the sensor, ideally away from the Tx and any receiver axes in a sled installation. Some GNSS receivers are likely to have a substantial EM signature and will need to be "surveyed in" or mounted farther away from the sled. For devices of this sort, it is vital that they remain immobile relative to the sensor or they will generate EM noise.

The EM sensor used in the R6™ is internally thermally compensated, so that its baseline or zero level should be stable at constant temperatures within its nominal operating temperature range. However, rapidly changing temperatures, such as those that occur when the instrument cools down from indoor temperatures to winter conditions, will cause transient base level errors that are likely to be strong enough to visibly affect measured EM output, particularly in resistive areas where small EM responses are expected.

Therefore, at the outset of a survey, unpack the sensor immediately and install it in its sled or cart housing at the survey base site to allow the sensor to come to equilibrium with local temperature conditions at the survey site. If the instrument is very warm or cool relative to its surroundings, 60 minutes is not too long for this equalization process. If the instrument was stored outdoors, rather than indoors, there may be less of a thermal change and a shorter acclimatization period may be acceptable.

Direct sunlight will have an effect on sensor internal temperature. Shifting the sensor from a shaded location to bright sunlight will typically induce a small transient thermal compensation error. Sun-shading the sensor is generally helpful if the sensor must be operated in conditions of alternating bright sunlight and shade. Slow changes in sunlight exposure (such as would occur over the course of many hours or a day) should be handled properly by the sensor’s internal compensation.

Importance of Base Site and Survey Loops

It is useful to establish a base site when working on a given site, to which the system can be returned frequently to monitor the stability of the instrument and to detect and correct for GNSS error. The easiest way to do this is to define one measurement site, preferably on a flat area, as a base, marked on the ground and preferably located by non-metallic stakes and flags.

Placing the survey sled on this location in the same orientation relative to the markings at the beginning and end of each survey loop should ensure that geometrical coupling changes relative to nearby non-layered soil structure does not change the sensor's EM measurement.

It is sometimes useful to shut down the instrument when a very long pause is required in data acquisition—this will reduce battery drain (and data storage requirements if data are being logged automatically.) At startup, the user should set up a new filename, as usual, and give the sensor a chance to get back to its operating temperature. The resulting separate data files can be appended to each other after unloading and transcription to facilitate GPS position drift or for plotting as a whole. If using a Geosensors Logger, acquisition can be "paused" using the Pause button on the iPad survey display, and "resumed" prior to continuing the survey. If using the sensor's internal menu system, the 4 key (in the Acquisition menu) will stop acquisition and the 1 key will resume acquisition.

If it is necessary for practical reasons to interrupt a survey loop, perhaps to acquire ground truth data, it is still worthwhile to acquire a complete loop to ease post-survey data QC and analysis, but for best results it is preferable to start and end acquisition at the same location.

If you pause to turn around at the end of a line, or for a few minutes at each site to collect a sample, instruct the logging computer to pause acquisition during data acquisition, then resume acquisition before starting again. The logged data unit will then display a time gap at the turn, which can be convenient during data processing.

Checking the Battery Charge:

The charge state of the power system (typically a battery pack) can be tracked via the battery voltage and current that are output in the PGSIA sentence.

Motorized Surveying and Survey Speed

A heavy sled or cart with rigid tow bar should be used if the R6™ is operated behind a vehicle—there would be safety and other issues with towing a lightweight sled or cart with a tow rope behind motorized transport, such as being struck from behind during sudden stops, losing control of the sled due to inadequate steering control, and so on.

While the data acquisition is capable of operating at sample rates of up to 40 Hz, many operators will choose a lower rate to reduce data volumes. For example, 1 Hz recording means that at a walking pace of 1 m/s, spatial sampling will be on the order of 1m. Operating at higher speeds will increase the spatial sampling interval proportionately, and increasing the sampling rate will decrease the spatial sampling interval. Be aware that faster sampling rates yield higher noise levels due to less time for filtering of each sample.

One way to think about required spatial sampling density is that it's desirable to have multiple samples per EM footprint. If the EM footprint is approximately two sensor lengths in diameter when the sensor is close to the surface, 1Hz sampling might be adequate up to a tow speed of 3.6 km/hr. However, there is little downside to storing data at higher rates, and it is always easier to record more data and filter/decimate it later than to deal with inadequate sampling density. Using matched EM and GNSS sampling rates is particularly helpful in this respect.

4.4 Power-off

It is not usually necessary to manually shut down the R6™ system. If using a computer logger, it is good practice for the user to stop data acquisition and transfer the data file to a backup volume before powering off. It is important to shut the system down before plugging in components such as the EM Sensor or the GNSS receiver, so that they are powered up together and thereby reduce the chances of electrostatic discharge (ESD) that could damage some system component.

4.5 Configuring Sensor Output

The sensor output can be configured using a Geosensors-supplied Python3 software tool. Settable parameters include:

1. Output Sample Rate can be set to values 40Hz, 10Hz, 1Hz, 10s
2. GPS output on or off
3. Xxxxxxxxxxxxx
4. (Need further description of <u>user version</u> of GCMCONFIG here).

5 Streaming Data

Survey data are recorded internally by a computer logger unit. When starting a new survey, the user should create a new file. When a survey is stopped, the resulting file should be closed. The user can then download this file from the logger to a computer or other device for viewing and exporting.

Once the data file(s) have been transferred to your computer, they can be transcribed from NMEA-style sentences to a more useful format. The contents of this file might look like the following:

```
$GNVTG,340.79,T,,M,0.955,N,1.769,K,A*2A
$GNGGA,192357.20,4352.71464,N,07849.99176,W,1,12,1.02,84.8,M,-
35.8,M,,*4C
$PGSI1,142341.791,+65.4,+0.38,+86.0,+1.04*07
$PGSI2,142341.791,+97.3,+1.99,+104.1,+3.28*32
$PGSI3,142341.791,+108.2,+7.18,+100.1,+13.51*31
```

$PGSIA,+12.11,+0.37,+20.6,+0.1,-2.1*7F
$GNVTG,340.84,T,,M,0.835,N,1.546,K,A*20
$GNGGA,192357.40,4352.71469,N,07849.99178,W,1,12,1.02,84.8,M,-35.8,M,,*49
$PGSI1,142341.991,+65.2,+0.38,+85.2,+1.03*09
$PGSI2,142341.991,+96.6,+1.97,+103.7,+3.25*3A
$PGSI3,142341.991,+108.4,+7.12,+100.3,+13.42*33

The sentence $PGSIE may be used in place of the three PGSIn sentences:
$PGSIE, 142341.991,6R2106,+65.2,+0.38,+85.2,+1.03,+96.6,+1.97,+103.7,+3.25,+108.4,+7.12,+100.3,+13.42*33

[This needs to be updated for the final version of output sentences]

where “6R2106” is the sensor ID (“6R” for “R6” followed by the sensor serial number).

If it is necessary to power-cycle the sensor during a survey (perhaps for an extended pause), be aware that the first few EM output sentences are affected by the power-on self-calibration. At low output data rates, this might only affect one or two samples worth of data, but at 40 Hz it may affect tens of samples. Therefore, after power-cycling, always pause for at least a few tens of seconds before restarting the profile. It will be generally be necessary to edit out the affected portion of output data from the survey dataset before making profiles or maps.

5.1 Connecting a computer or data logger to the R6™

An RS232 serial interface is required in order to directly unload data or communicate with the R6 for other purposes. Since most up-to-date computers, particularly laptops, do not provide RS232 ports, it is usually necessary to use a USB-Serial adapter of some sort. On a Windows device, the adapter will generally have been configured during its installation to act as COMn, where n must be determined: this can be checked and changed through the Control Panel/System/Device Manager/Ports/Advanced menu when the device has been plugged into its USB port. On Mac and Linux systems, a different naming convention is used for serial port adapters.

On some computers, plugging the interface cable into a different USB port may change the serial port’s operating parameters, including its COM port number. The same USB port should therefore always be used to eliminate this possibility. As a convention, the top, left, front USB jack on laptop computers should always be configured to use with the USB-Serial adapter—this should minimize the number of COM port mismatches that are encountered.

The serial port adapter should connect to the female DB9 plug on the Data/Power Cable, while the M12 connector at the other end of this cable attaches to an adapter to the M12 main sensor connector.

5.2 Inspection and Maintenance

The R6 requires minimal maintenance. The sensor housing is sealed against the entrance of dirt and water, as long as a suitable cable is properly attached to the sensor's main connector.

If ice, water or dirt are allowed to accumulate in the socket of the main connector, this may lead to entry of contaminants into the sensor housing. Keep the connector covered when not in use. Check cable plugs before attaching them to ensure that they are not dirty or wet. Dry compressed air can be used with care to gently blow out dirt that has accumulated in connectors.

The R6 sensor was designed to be cart-mounted. It can therefore tolerate moderate shocks such as are typical in such installations. It was not designed to withstand physical abuse such as unprotected drops onto hard surfaces or striking hard objects such as fence posts or stumps at greater than walking pace. In particular, the main connector can be damaged if the connector end of the sensor is rammed into an object—this could happen at any speed, so care should be taken to prevent such collisions.

If the R6 is mounted onto a sled, non-metallic vibration-damping mounts should be used to reduce vibration and shock-induced accelerations of the sensor during survey operations.

The outer housing of the sensor may be cleaned when necessary using a cloth or sponge with a mild detergent and water. Do not use other solvents, and never clean an R6 with a power washer or high-pressure spray, as this may damage the seals that keep water and other contaminants out of the sensor interior.

6 Troubleshooting Guide

The R6™ is a small, lightweight GCM developed specifically for shallow EM sounding surveys. It is rugged enough to be used in motorized surveys, but as with any electronic sensing device, it can be damaged by impacts, exposure to moisture, and extreme heat.

> NOTE: The R6™ is a factory sealed unit that contains no user-serviceable parts: unsealing or opening the unit will damage its calibration and void its warranty. Service of the internal components of the sensor must therefore be performed by Geosensors in order to safeguard its accuracy and integrity.

The most frequent factors causing difficulties during field surveys with EM sensors fall into three main categories: electrical and connection issues, mechanical issues relating to the survey platform, and EM interference.

6.1 Electrical, Cables and Connection Issues

The most vulnerable elements in most EM sensor systems are the cabling and connectors linking the various components. The internal connections of the R6™ hardware have been secured and stabilized as much as possible, and every effort has been made to armour and seal the sensor package and to protect its connector and battery packs. However, the connection between the Logger (or external computer) and the R6™ package is vulnerable in several ways:

1. the cable can be crushed or cut;
2. the cable’s plug can be compromised in cold conditions by being dropped into snow before being mated with the sensor jack; and
3. its conductors could be subject to fatigue or breakage if the cable is tightly secured (for example, to the sled) and then flexed excessively with a small radius at that point.
4. if the cable is pulled hard, the conductors could be damaged, or the contacts inside the connector could be pulled out of registration. Either situation could make it difficult or impossible to operate the system, so spare cables should be carried at all times.

For these reasons, the cable should never be stepped on, kinked or run over by vehicles, and care should be taken to avoid catching it between obstructions.

It is good practice to secure the cable to the sled loosely (*e.g.* with velcro straps) at several points on either side of a more secure attachment point (*e.g.* a couple of turns of black tape) in order to minimize fatigue. A service loop between the sensor and the securing point should be left to ensure that the cable is never pulled away from or bent sharply at the plug.

The same considerations apply to all of the vehicle extension connectors and cable. Always leave a substantial service loop near linkages, such as at the sled-sensor gap or the tow bar-hitch gap, and always provide adequate strain and fatigue relief at these locations. (Obviously the loop itself should be protected against snags.)

If possible, run the cable through a flexible conduit that is secured to the vehicle and sled/cart. If done correctly, this can essentially eliminate cable problems arising from snags and crushing events.

> NOTE: It is important to attach the data logger or Data Cable to the main R6™ jack before connecting the battery pack or external power to the logger or Data Cable to power up the unit. If the battery pack is connected first, then when the logger or Data Cable is attached to the R6™, arcing may occur at the terminals of the connector plug, damaging the protective gold plating on the terminal pins.

If the sensor is stored outdoors between surveys to minimize thermal acclimatization time at survey startup, ensure that the connector jack is covered and sealed (the plastic protection plugs that have been supplied, or a strip of black electrical tape that covers the opening and is secured by a turn or two of tape around the connector will do this) to prevent snow or moisture from entering the connector jack. Leaving the Logger cable connected to the unit but without its battery pack installed will serve the same function, but the other end of that cable should be protected in the same way. If the jack does get wet, flip the instrument or cable up so that gravity will assist in drainage, blow the snow or water out of the connector as well as possible, and if necessary, take the sensor inside, let it warm up, and dry out the connector thoroughly. NEVER use a heat gun to dry out the connector—it will lose its weatherproof properties and will likely damage the wiring on the back side of the connector as well.

For the main connector of the R6™, since it is located on the end of the instrument, it can be vulnerable to damage by stumps or plant stalks that are straddled by the sled's runners. This can be averted by using an ABS plumbing fitting such as a sleeve or reduction joint, with nominal ID 3 inches, which will just slip onto the end of the instrument when warm and protrude beyond the end sufficiently to provide protection. The protective fitting should be taped or otherwise secured to the sensor housing to prevent it from vibrating free. As always when working with an EM sensor, no metal objects, fasteners, or other conductive materials should be present in the vicinity of this fitting.

M12 Cable Wiring

M12 Cable	Description	For Reference: Turck Cable
Blu	+12VDC Power	Red
Brn	GND	Green
Wht	SensorTx/LoggerRx	White stripe on red
Blk	SensorRx/LoggerTx	Black stripe on red

6.2 EM Interference

The strongest form of EM interference that may be observed would arise from the presence of nearby ground conductivity meters (GCM's), such as R6's or other Geosensors-manufactured sensors (including Dualem™ instruments), and possibly from non-Geosensors GCM's. This interference is caused by pickup of the transmitted signal of these other sensors at the precise operating frequency of the R6. Geosensors-built GCM's should be operated with a minimum inter-sensor distance of 200m to avoid these effects, unless they operate at different frequencies.

Interference from power lines is sometimes observed, but is usually limited to the immediate vicinity of the power lines. Surveying very close to or immediately beneath power lines, particularly high-voltage power lines, is likely to yield noisy data in those locations.

Interference from electric fences can be a strong and perplexing noise source. Ask for the operators of the site being surveyed to turn off nearby electric fences during survey execution.

If utilized, the electrical connection between the R6™ and a power source such as a vehicle alternator is a potential source of noise. The sensor power interface has been engineered to minimize this effect, but if noise is observed, particularly when the sensor is not moving, it would be worth connecting the battery pack, disconnecting vehicle power, and looking for a drop in noise levels. If vehicle power noise is suspected, one or two 12V batteries connected in series and carried at the back of the vehicle could be used in place of the vehicle power. It will be important to charge these batteries frequently in cold conditions.

Another important source of "interference" is proximity of the sensor to metallic objects. While the most troublesome objects are substantial objects like metal packing cases or vehicles, even a length of steel rod, rigging wire, a pipe or an auger segment within tens of centimetres (a larger radius for a larger/longer object) of the instrument will cause EM errors, typically changes in the EM inphase response but sometimes affecting the quadrature channels as well.

Bringing the sensor close to large objects like vehicles, reinforced concrete structures or pads, and ladders or metal-clad or metal-framed buildings, will cause substantial EM errors that will be reflected in the measurements. The two-segment tow bar is the minimum length that should be used when vehicle-towing the instrument, and some vehicles will still generate anomalies in the sensor at this separation.

Metallic fencing, including mesh, chain link and barbed wire, can sometimes generate strong anomalies. These are likely to be strongest when the fencing is directly connected to metal posts that are driven into the ground. Ungrounded fencing stapled to wooden posts is often less troublesome.

Metallic objects, including battery packs, should never be mounted to or carried on the sleds. It is also not advisable to put coats or other items on top of the sensor or sled when it is running, as conductive objects in the pockets, or even metallic elements of the coat’s structure or lining, could cause EM errors due to their proximity to the sensor.

6.3 NMEA-Mode Operation

This system is operated in a special “NMEA” automatic output mode designed for routine surveying, particularly with motorized or unattended operation, with data logging to a computer or external data logger. In this mode, the sensor outputs streaming EM, orientation and GPS data in NMEA-style sentences, rather than responding to individual user requests via key presses on a user interface. If operating the system from a logging computer, the logging computer should be configured with a terminal program such as Hyperterminal , CoolTerm or Tera Term as well as the logging software.

6.4 Changing Sensor Operating Parameters

A Python 3 program called GCMCONFIG is used to adjust sensor settings such as output data rate, enable or disable specific data sentences, and so on. This program is not required to operate the sensor, however: powering up the sensor will initiate NMEA-mode data output after a few seconds.

Appendix A: Output Data Formats

Standard NMEA-style data outputs for the R6 and other new R-series sensors are PGSII, PGSIE, PGSIA and PGSIB, plus flow-through sentences from the built-in GPS receiver (when present).

The R6 can also output PGSI1, PGSI2, PGSI3 sentences. PGSI1-3 are obsolescent, and are only included for backwards compatibility with the previous generation of sensors.

PGSII

- PGSI are information sentences that describe the sensor but are not typically used for data processing

PGSIE

$PGSIE,204658.000,6R2106,7.37,0.08,1.99,-0.02,0.22,-0.01,0.51,-0.07,0.58,-0.12,0.34,-0.11*14

hhmmss.sss, IDStrng, ECa1,MSA1, ECa,MSA, ECa,MSA, ECa,MSA, ECa,MSA, ECa,MSA *CS

- PGSIE is the principal sensor output, comprising timestamp hhmmss.sss, sensor ID string, and six pairs of ECa and MSa (QD and IP) values for channels 1 through 6.
- * symbol denotes beginning of two-hex-number checksum

PGSIA

$PGSIA,10.87,0.48,50.50,0.49,80.03*4A

bb.bb,i.ii, t.tt, ppp.pp, rrr.rr

The PGSIA auxiliary data sentence comprises

- +bb.bb battery supply voltage
- +i.ii battery supply current
- +t.tt internal temperature in degrees C--length of this field will vary at higher temperatures
- +ppp.pp pitch of sensor axis above horizontal in degrees
- +rrr.rr roll about long axis of sensor in degrees. Roll is positive down on right side of sensor, in forward direction when looking from Rx to Tx
- pitch and roll are output over the range +/- 360
- * symbol denotes beginning of two-hex-number checksum

GPS flow-through sentences.

(examples here)

Obsolescent Sentences:

The data fields for the PGSIn sentences, with n=1-3, are

- timestamp in format HHMMSS.sss
- ECa and inphase for first separation in group, separated by commas from each other and from other fields
- ECa and inphase for second separation in group
- * symbol denotes beginning of two-hex-number checksum

PGSI NMEA Sentence examples:

```
$PGSI1,145428.812,+27.4,-0.43,+31.9,-0.05*03
$PGSI2,145428.812,+36.5,+0.47,+39.4,+1.11*04
$PGSI3,145428.812,+43.1,+2.13,+42.4,+2.94*02
```

Appendix B: Geosensors R6™ Technical Specifications

1. One EM transmitter operating at a single frequency in the vicinity of 9 kHz (specific operating frequencies of 9000, 8400, 8700, 9300 or 9600 Hz should be specified at time of order. 9600 Hz will require a special order. Other operating frequencies may also be possible but would also require a special order).
2. Six EM receivers, coplanar with the transmitter and with transmitter-receiver distances of 0.5, 0.7, 0.9, 1.1, 1.5 and 1.95m. The sensor can be operated in Horizontal Coplanar or Vertical Coplanar mode (or in another, user-selected pitch and roll mode if desired).
3. Maximum EM noise levels obtained during a static test in horizontal coplanar orientation in an electromagnetically quiet location have been measured as less than 10 ppm at 0.5m, 30 ppm at 0.9 and 1.1m, and less than 100 ppm for all separations at 40 Hz output sampling.
4. EM dynamic drift levels: typically less than ±1.5 mS/m in quadrature channels and ±0.1ppt for inphase channels for slowly varying temperatures over a 3 hour interval. Drift error will be higher following rapid temperature changes. The optimal ambient temperature range for operation is 0 to 30C: slight increases in drift error may be observed outside this range.
5. Data output is provided as proprietary RS-232 NMEA-type ASCII strings at 115200 baud, with a maximum user-settable output rate of 40 Hz. The unit ships with a standard output sample rate of 1 Hz. This can be adjusted by the user using the GCMConfig software tool (provided).
6. When activated, the internal GPS receiver (assuming good satellite constellation visibility) will provide a very precise pulse-per-second signal to internal systems for synchronization purposes. Positional accuracy should be on the order of 10m or better after warmup
7. Static pitch/roll outputs will be accurate to approximately 1 degree, with pitch/roll precisions of 0.01 degree.
8. Internal temperature accuracy approx. 1 degree C, with temperature sensor output precision 0.06 degree. Internal temperatures will not match externally measured temperatures due to heat production from sensor electronics.
9. Physical: length 2.41 m (94.9 inches), outer diameter 0.089 m (3.5 inches) outer. Weight 7 kg (15.5 lb). Sensor is weatherproof when the data/power connector is installed, but it should not be immersed or otherwise subjected to pressures higher than 1 ATM when wet.
10. Power: 12VDC nominal operating voltage. Can operate with input voltages between 10VDC and 28VDC. Typical power consumption approximately 4W.
11. Coil locations: relative to the outer surface of the transmitter (main connector) endcap, the transmitter coil is centred at 0.353m, and the receivers are centred at 0.853, 1.053, 1.243, 1.453, 1.853 and 2.303m. The Tx-Rx midpoints are located at 0.603, 0.703, 0.803, 0.903, 1.103 and 1.328m from this reference point. The internal GPS and Wifi antennas are located at approximately 0.65m and 0.53m from this reference point.

Installation Notes:

1. External mounting points should be located away from coil locations and GPS/wifi antenna positions.
2. Any conductive or magnetically susceptible item in the general vicinity of the sensor will affect the EM sensor output, and are particularly to be avoided near coil and antenna locations.   Plastic fasteners should be used wherever possible.
3. Some carbon fibre parts are electrically conductive: test all such parts for EM response before using them.
4. Metal fasteners, pins, structural elements and any other metallic items should be kept as small as possible and should be made of non-magnetic stainless steel to minimize their EM response.

Appendix C: Manufacturer’s Contact Information

Please contact Geosensors Inc. as follows:

Mail or Courier:

Geosensors Inc.
Attn: Scott Holladay
66 Mann Ave
Toronto, ON M4S 2Y3
Canada

For all GCM or R6™ related questions, please contact Scott Holladay

Tel: 416 483 4691
Mob: 416 892 0382
Email: Scott.Holladay@geosensors.com

For assistance with shipping or with mechanical issues or questions, contact David Lalonde:

Tel: 416 891 9667
Email: David.Lalonde@geosensors.com

NOTE: The R6™ is a factory sealed unit that contains no user-serviceable parts: unsealing or opening the unit will damage its calibration and void its warranty. Service of the internal components of the sensor must therefore be performed by Geosensors in order to safeguard its accuracy and integrity.

VERY IMPORTANT:

Please do not ship items for repair or warranty service without making prior arrangements with David Lalonde. It is vital that incoming shipments are accompanied by the correct shipping and customs documents. Incorrectly documented shipments are likely to result in substantial taxes or other fees that will be billed to the sender.