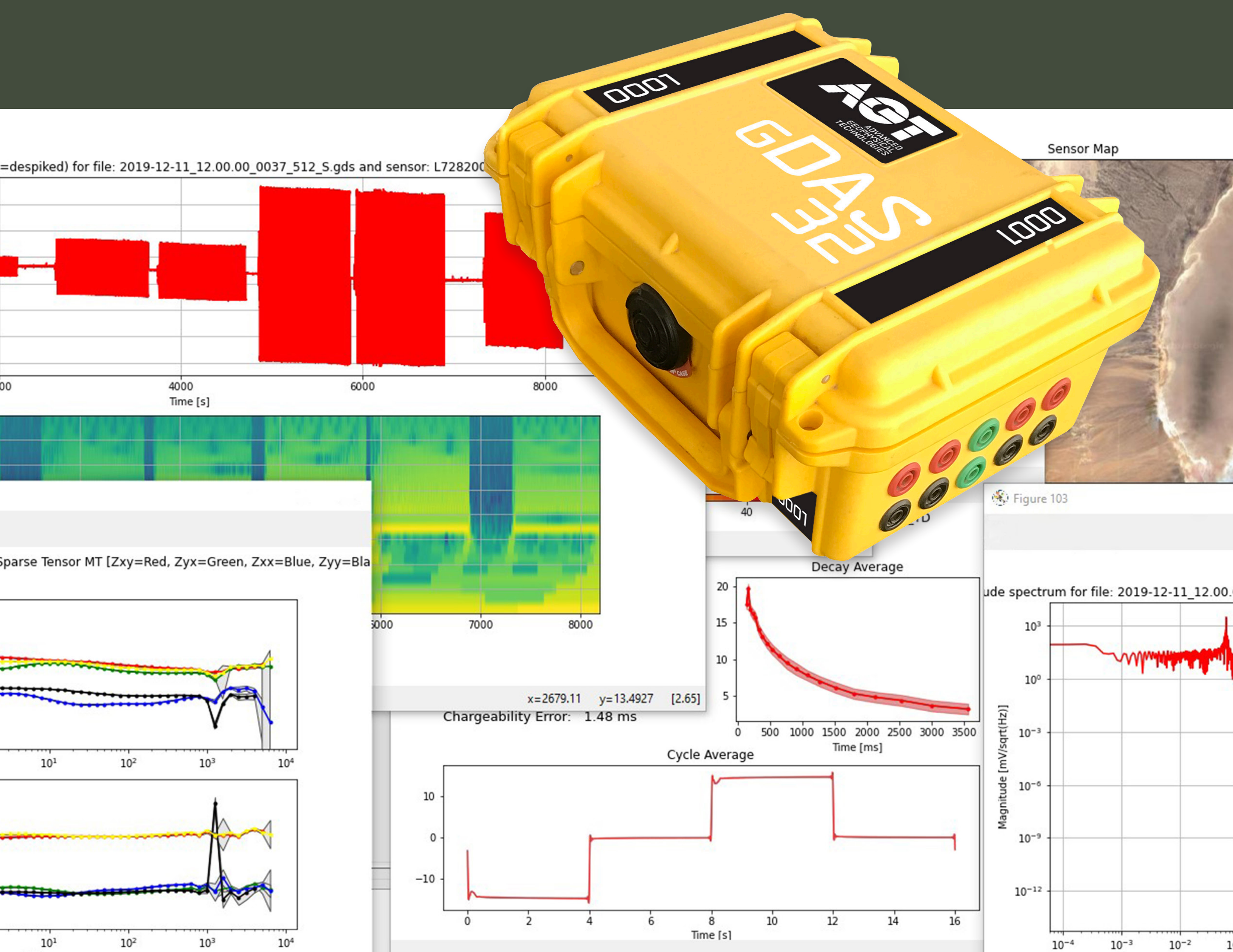
SOUTHERNROCK GEOPHYSICS

AGT ADVANCED GEOPHYSICAL TECHNOLOGIES

gDAS32 GEOPHYSICAL DISTRIBUTED ACQUISITION SYSTEM APPLICATION EXAMPLES AND NOTES

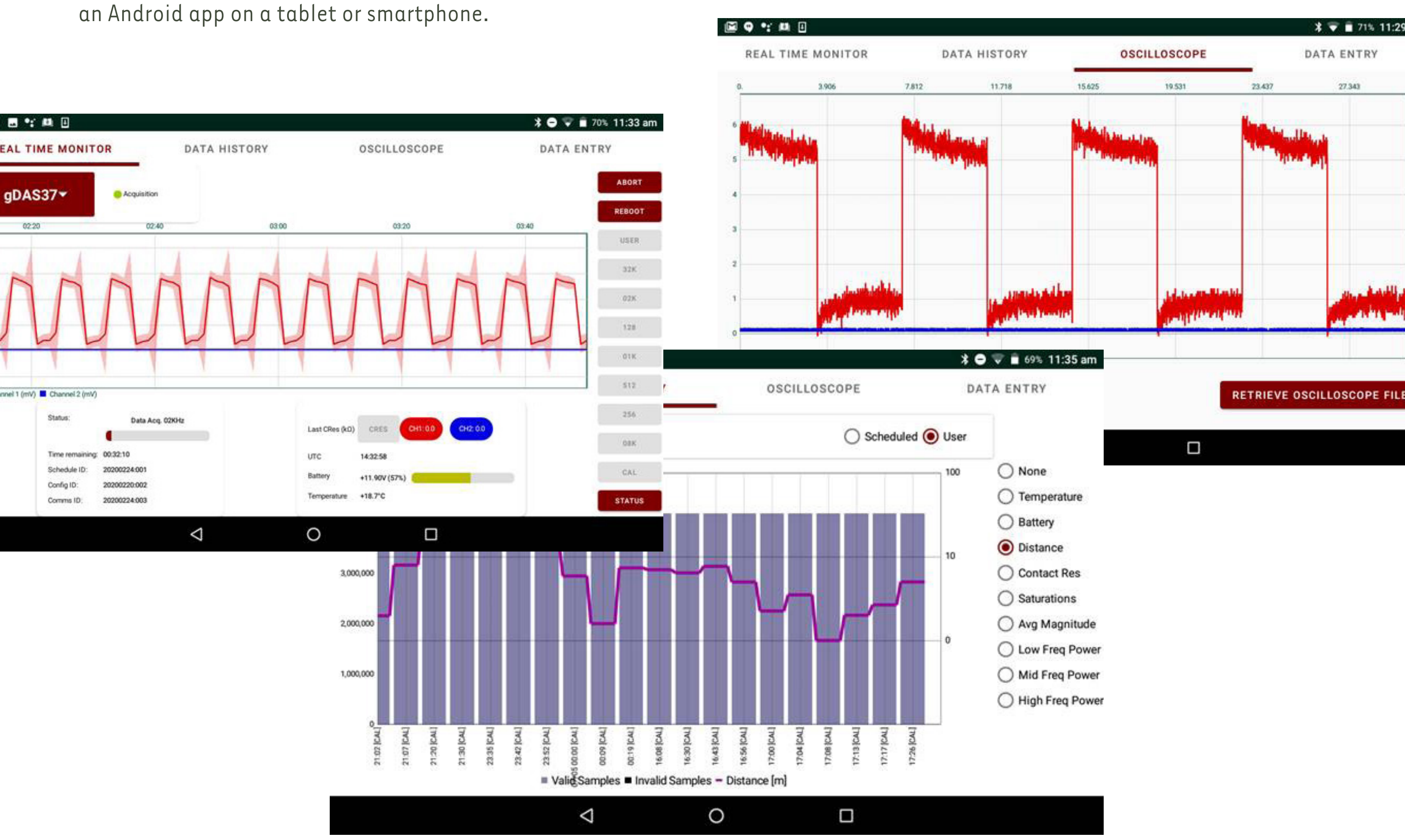


OVERVIEW

The gDAS32 has been designed as a highly flexible, high resolution, low noise instrument for time series data acquisition using grounded E-field dipoles, induction coils, ungrounded dB/dt loops, and magnetic field sensors such as fluxgates and SQUID sensors. A very broad range of geophysical surveys can be carried out using the gDAS32 both in terms of methodology as well as array style and specifications.

gDAS32Pro software facilitates the data management, processing, and analysis right through to output of the results in standardized formats for inversion modelling and integration.

Each gDAS32 instrument has two independent channels with 32-bit ADC's suitable for both grounded E-field dipole and other sensor types. The sample rates and other settings may be defined by the user but are typically standardized at 128, 512, 2048, and 32768Hz. Acquisition of the time series data may be launched manually by the user or according to a schedule which is uploaded into each unit, usually with each interval of time series data extending over 4 million samples per channel. At a sample rate of 32kHz this has a duration of just over 2 minutes whilst at 128Hz the duration is a little over 9 hours. IP data is often acquired at a sample rate of 512Hz.
Extremely precise synchronicity is achieved across array instruments using the GPS-PPS signal providing very high phase accuracy through to high frequency (nominally 10kHz). The instrument is environmentally sealed and extremely robust. Low power consumption provides lengthy autonomy with standard Pb-acid or Li-type batteries, easily extended with the addition of a solar panel to become unlimited. All user interaction with the gDAS32 is via radio (Bluetooth or extended range radios), generally using an Android app on a tablet or smartphone.



INDUCED POLARIZATION with/without MT

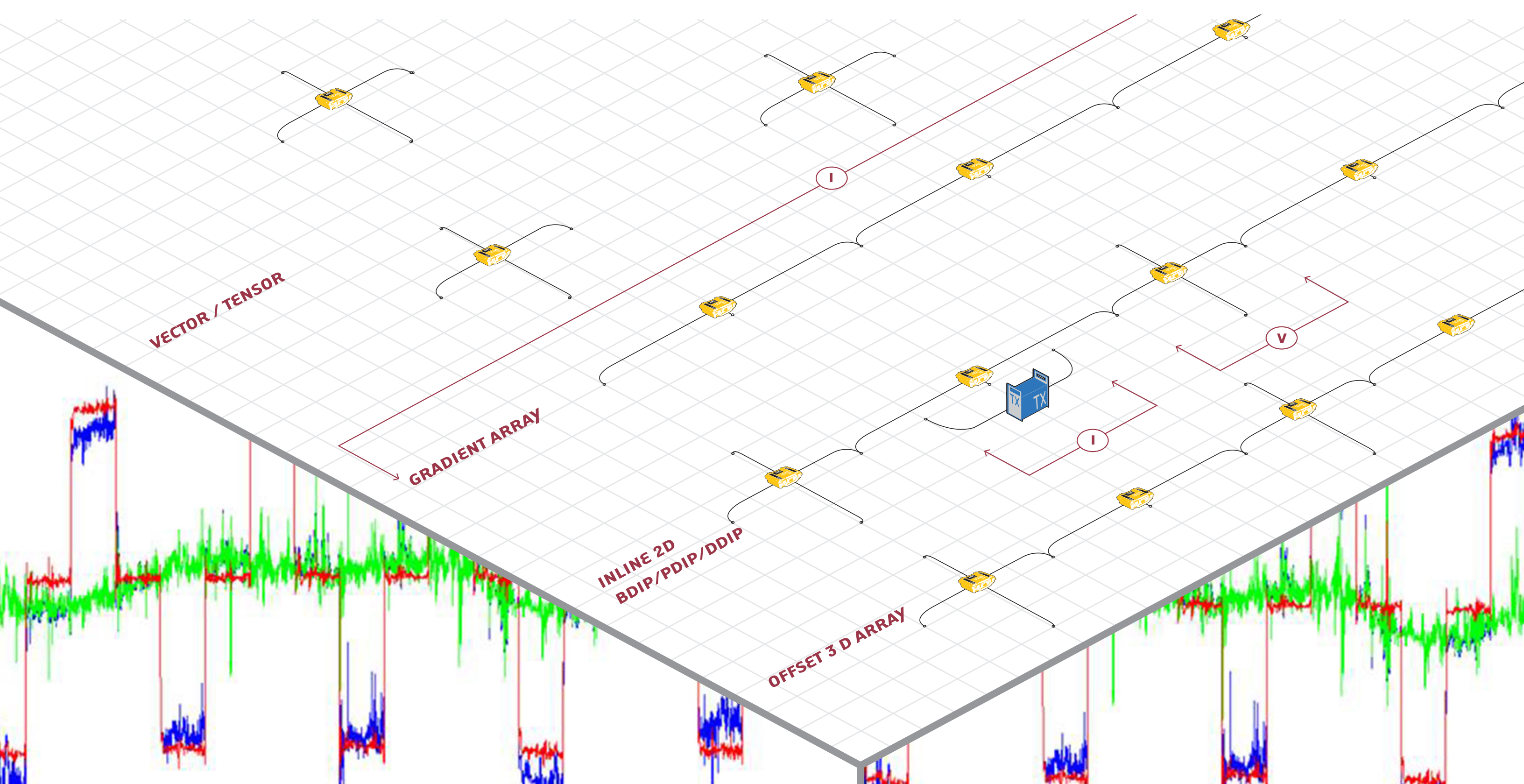
In this description of Induced Polarization (IP) and "DC" Resistivity we are referring to both Time Domain acquisition as well as Frequency Domain or Complex Resistivity acquisition. Indeed, both may be obtained from any acquisition since synchronous time series data monitors the output current signal from the transmitter with an additional gDAS32 and a purpose-built current sensor. This permits the use of any transmitter system and any transmitted waveform even those which are not necessarily well controlled or synchronized. IP data may be processed to chargeability, phase, extrapolated ("decoupled") phase or Cole-Cole or other IP-model parameters.

Base frequency(ies) for the transmitted signals may be selected according to the type of survey and environment, so for example in conductive areas with large dipoles and transmitter-receiver spacings it is common to use 16s cycle periods to combat the eventual influence of inductive electromagnetic coupling, but with smaller scale surveys in more resistive terrains higher base frequencies may be appropriate.

It is often useful to leverage the installation of IP arrays to also acquire Magneto-Telluric (MT) data with the addition of magnetic field sensors. Although the time series data acquired during the injection of current may be used to obtain MT impedance data it is usual to utilize time series data acquired during intervals when the transmitter is not in operation and/or simply leave the gDAS32 instrumentation installed overnight after acquiring IP data for broadband MT data acquisition under often ideal nocturnal conditions while the crew is at rest.

The MT impedance data is of itself useful in providing relatively detailed resistivity models through 1, 2 and/or 3D inversion as well as a wealth of structural information etc. but these impedances may also be used, together with data from a distant H-field remote reference site, to infer the telluric electric fields for each IP receiver dipole such that it may be subtracted from that time series data reducing an often dominant source of noise from the IP data. This process is commonly referred to as "Telluric Cancellation".

The classic Dipole-Dipole and Pole-Dipole arrays used for IP acquisition, as well as the slightly more unusual Bipole-Dipole or Pole-Pole arrays, are an efficient way to obtain relatively high spatial resolution 2D imaging. With a set of survey lines the dataset may well also be appropriate for 3D inversion. Inline DDIP or PDIP was read with n-levels (Tx-Rx separations) extending from 1 through 6 (times the dipole length) restricting the depth of investigation typically to about 2.5-times the dipole length. Modern systems, like the gDAS32, may be used to acquire data to much larger n-levels (n~25) increasing the depth of investigation to around 5-times the dipole length (e.g. a 200m DDIP array may provide information to about 1km depth), and efficiently ensure acquisition of reciprocal senses of the Tx and Rx dipoles.



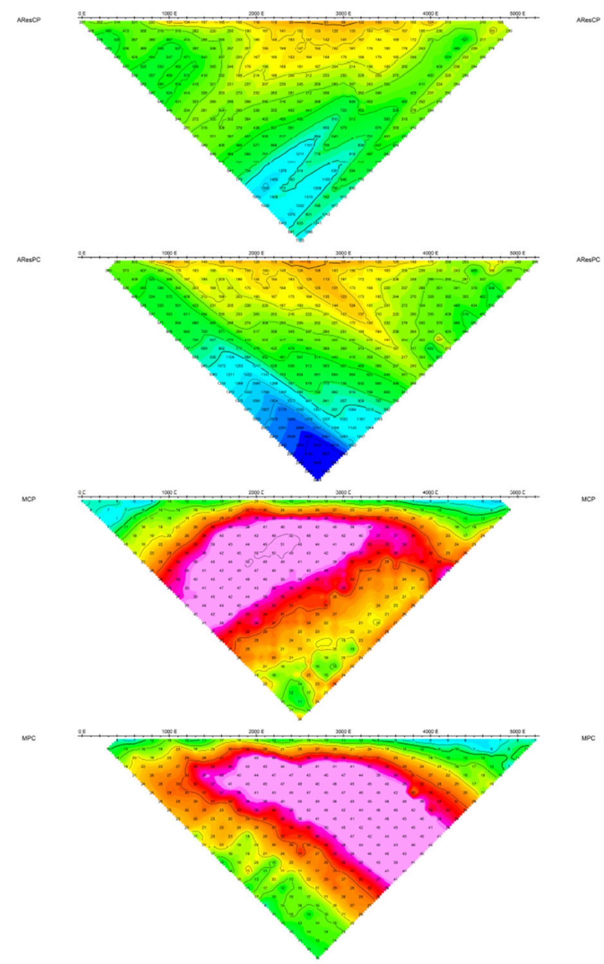
INLINE & OFFSET DDIP OR PDIP

Often one or more complete survey lines will be populated with gDAS32's, each acquiring time series data on two of the contiguous E-field dipoles (no overlapping Rx-cabling is required), with say a 4km line having 20 x 200m dipoles being read by 10 gDAS32 instruments.

The gDAS32 instruments acquire time series data constantly and relevant intervals are then used in the post-processing. Contact resistances, time series data and other metrics can be monitored using the radio/Bluetooth connectivity of each unit during all stages of the survey. The injected current is recorded as precisely synchronized time series data with an additional gDAS32 and iSense.

A few more gDAS32 units may be used to acquire H-field data usually at a few sites with orthogonal pairs of induction coils providing "EMAP"-style MT data acquisition and for use, together with a distant remote reference site, in Telluric Cancellation. Furthermore a few sites with orthogonal E-field dipoles may be incorporated into the array to provide a few Tensor MT sites where a more complete analysis of dimensionality, etc. may be undertaken.

Very similar to the description of In-line DDIP or PDIP (section 3.1.1), the transmitter and receiver dipoles and/or poles may be located on offset lines. In practice, surveys are often run by installing gDAS32's on three consecutive and parallel lines (1,2 and 3) while the transmitter injects current into dipoles or poles along the central line (2). Instrumentation from the first of the three lines is then hopped over and installed on the fourth line (for Rx on lines 2, 3, and 4) for injection of current on the next line (3). This provides both inline and offset data for every line in the grid, and may provide additional constraint on 3D inversion modelling.



Inline DDIP pseudosections from a single survey line of 200m dipole data reading n=0.5 through 25.5 levels, showing apparent resistivity (upper two pseudosections) and chargeability (lower two pseudosections) for Tx trailing and leading Rx in each case

Again, it is easy to add H-field, orthogonal E-field, and/or remote reference acquisition to the array for MT acquisition and Telluric Cancellation of the IP data.

GRADIENT ARRAY IP

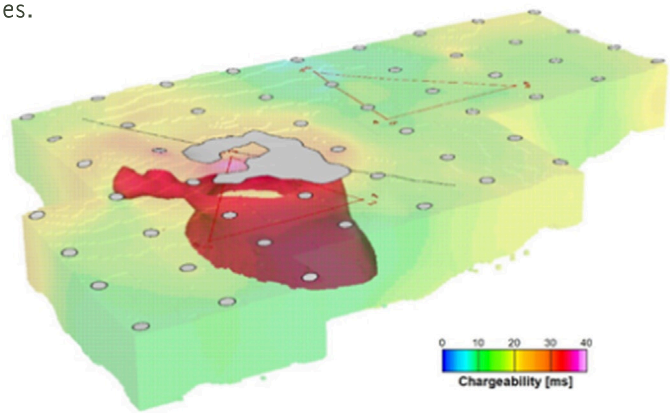
The gradient array can be a highly efficient method of obtaining detailed "profile" responses on a grid of lines, particularly appropriate for narrow targets with relatively long strike where the depth to the targets is of lesser importance than resolving their lateral location and continuity. The incorporation of H-field acquisition to provide "EMAP"-style MT data for 1 and 2D inversion modelling of resistivity may assist in interpreting the results of both datasets in a sectional manner.

Given that a relatively large area is covered with just a single transmitter bipole surveying may advance very rapidly even with very small receiver dipoles, providing excellent lateral resolution particularly.

VECTOR / TENSOR IP

The vector/tensor IP (VIP) array is arguably a style of 3DIP array, but specifically utilizes an orthogonal pair of E-field dipoles at each receiver site and a relatively small number of transmitter bipoles. Receiver sites are usually on a fairly widely spaced grid. The separation of the grid of sites is chosen as a function of the target foot-print, certainly not exceeding the smallest target of interest but usually aiming at minimizing any data "redundancy" in the interests of covering the largest area in the shortest time possible. The use of an orthogonal pair of receiver dipoles at each site permits the measurement of the vector of the E-fields and by extension, the vectors obtained from different transmitter sources may be used to obtain tensor parameters. Often six transmitter bipoles are used for coverage of a relatively large area, constructing these from just four contacts organized in a roughly square formation. Some overlap of measured receiver sites is recommended from adjacent transmitter blocks.

The paucity of data throughout the surveyed area with small transmitter to receiver separations results in there being little constraint on the depth to anomalous responses, however it has been found that 3D inversion may be effectively brought to bear on resolving the, at times, complex distribution of responses to provide reasonably well-constrained definition of the lateral location and extents of domains of contrasting physical properties.



3D inversion model of the vector chargeability response using data from all 6 transmitter bipoles highlighting an isosurface at 30ms which very closely coincides with the location and extents of the Atlantida porphyry Cu-Au minerlization.

The grids of orthogonal E-field dipoles are well suited to the inclusion of sparse or full compliments of H-field sensors for the semi-simultaneous acquisition of (sparse) tensor MT data and application of telluric cancellation. Resistivity models through 1, 2 and/or 3D inversion of the MT data may be used as constraints on the otherwise poor vertical definition obtained from the 3D inversion of the VIP alone.

This methodology is highly effective at rapid ground coverage for relatively large targets with roughly circular footprints, such as Andean-style porphyry copper deposits. Highly elongate targets, for example, may not be well explored for by this methodology.

As for all IP techniques the dominant factors determining the depth of investigation are the transmitter to receiver separation and the dipole lengths, so it may often be expected that depths of investigation of around 1km may be achieved, as always with a series of caveats related to target-host resistivity contrasts, geometries, etc.

OTHER 3DIP ARRAYS

An unlimited variety of arrays may be read where many receiver dipoles on a regular (orthogonal) grid or even, for example in very rugged topography, placed arbitrarily where access permits are read from a number of transmitter dipoles or poles located within or around this array of gDAS32's, all with an aim to utilize the data in 3D inversion modelling. Very large numbers of transmitter-receiver (Tx-Rx) pairs may be rapidly acquired in this manner which may assist in constraining 3D inversion models.

Again, it is easy to add H-field, orthogonal E-field, and/or remote reference acquisition to the array for MT acquisition and Telluric Cancellation of the IP data. Quite how many and how they are distributed is a function of the target types and the physical and geological environment.

A broad and irregular 3DIP approach, with MT and in some instances CSEM, has been used on a number of projects where access is complicated by the presence of on-going mining operations and/or severe topographic relief. Alternatively, detailed regular grid arrays may be used where maximal constraint is required.

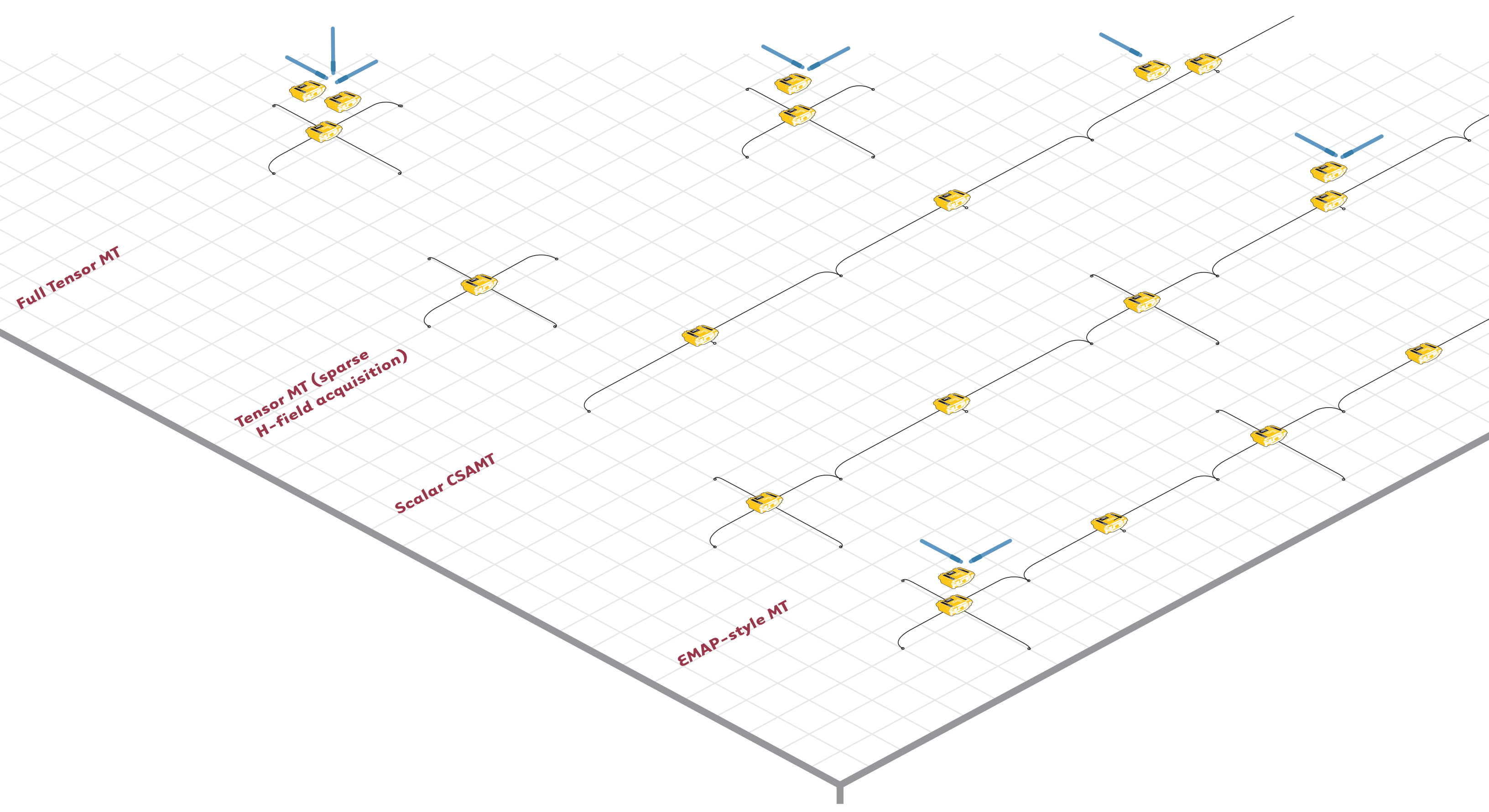
MAGNETO-TELLURICS

Although much Magneto-Telluric (MT) data is acquired in conjunction with an IP survey, MT may also be a highly effective tool in its own right providing both excellent imaging of resistivity through 1, 2 and 3D inversion as well as providing a wealth of information regarding structural texture, off-survey anomalism, etc. through dimensionality analysis of skew, phase tensors etc.

MT may be thought of as a collection of methodologies extending from Controlled Source Audio-frequency Magnetotellurics (CSAMT) through to full tensor, remote referenced broadband Magnetotellurics. The gDAS32 is suitable to the full range. The selection of array, sensor types (particularly the bandwidth of the H-field sensors), eventual use of controlled sources, and acquisition bandwidth is subject to the purposes of the particular survey. Although not easily pigeonholed

- If the bandwidth of interest extends between around 1 a 10000Hz it is reasonable to use high-band induction coils (eg. Zonge ANT-6) and short acquisition intervals of perhaps just a few minutes for each site. A controlled source maybe used to "infill" the impedances around 2kHz where natural signals tend to be weak. A controlled source may be used,as in CSEM and/or CSAMT, where this entire bandwidth may be severely degraded with cultural interference, in a mine-site for example.
- For bandwidth extending down to around 0.01Hz (100s) low band induction coils (eg. Zonge ANT-4) are effective although these coils often limit high frequency data to around 500Hz. Longer intervals of data acquisition are required, often ideally extending overnight.
- For much lower frequencies, induction coils begin to become ineffective and fluxgate or SQUID sensors may be used.

Given the typical 3D complexity of the impedance tensor at low frequencies, broadband MT surveys usually utilize a tensor approach whilst for some applications of Audio-frequency band MT the efficient acquisition of contiguous dipoles for mapping relatively narrow features may favour an "EMAP"-style array, particularly if this is also being installed for IP acquisition.



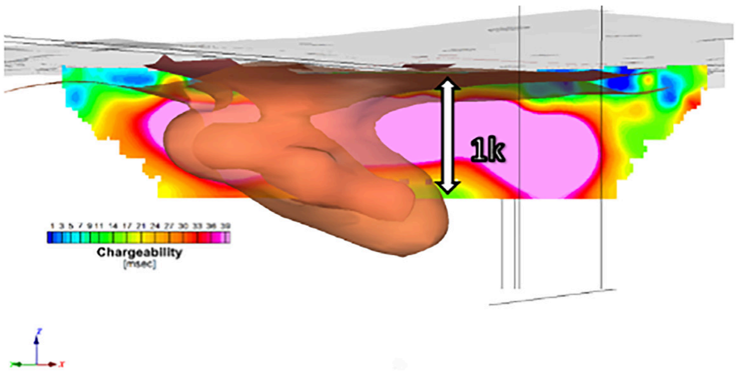
The use of a remote reference site is recommended (generally comprised of an orthogonal pair of H-field sensors) although for some applications mutually referencing within the acquisition grid is adequate without recourse to a dedicated (fixed) remote reference as long as the noise in these mutual reference sites is not correlated.
Induction coils are relatively costly and with the advent of systems like the gDAS32 where numerous essentially autonomous acquisition devices can be used in parallel a strict requirement for the acquisition of 3-components of the magnetic field at each E-field site may make a survey expensive or restrictive in terms of the number of sites that may be occupied at any one time. The use of "sparse" surveys where groups of E-field sites utilize a common H-field site rests on an assumption that the horizontal H-fields vary little over this more extensive area. Although this is not an appropriate assumption for all target types and geological settings, there are many instances where it is acceptable, greatly enhancing the productivity that may be achieved. As a general rule-of-thumb, broad mapping of resistivity variations and detailed "EMAP"-style acquisition for cross-cutting resistive targets are conducive to a "sparse" approach, whilst targeting good conductors may require a higher spatial density of H, and Hz, acquisitions where the majority of the response may be represented.

FULL TENSOR MT

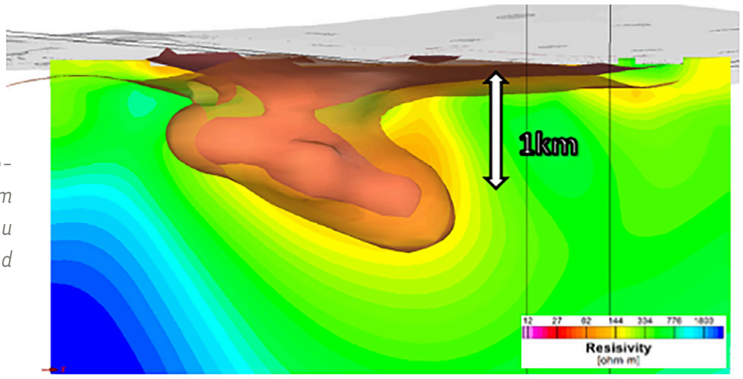
Each site is comprised of an orthogonal pair of E-field dipoles, and orthogonal horizontal and vertical H-field sensors, using three gDAS32 instruments to read these 5 components. Sites may be located at anywhere from a few hundred metres apart to tens of kilometres according to the scale of the survey. A dedicated or mutual remote reference may be used with all instrumentation acquiring data synchronously according to a pre-defined schedule.

SPARSE TENSOR MT

Acquisition is done in a similar manner to a Full Tensor MT survey but some sites are acquired with a single gDAS32 only acquiring data from an orthogonal pair of E-field dipoles under the assumption that the horizontal H-fields are similar at a "nearby" site where a Full Tensor setup is installed. Vertical H-fields may be incorporated at some or all sites



2D Inversion Chargeability Section PDIP data cut to a depth of 1km through the centre of the Atlantida Cu-Au Porphyry, with conductive shell from the broad 1km grid of MT

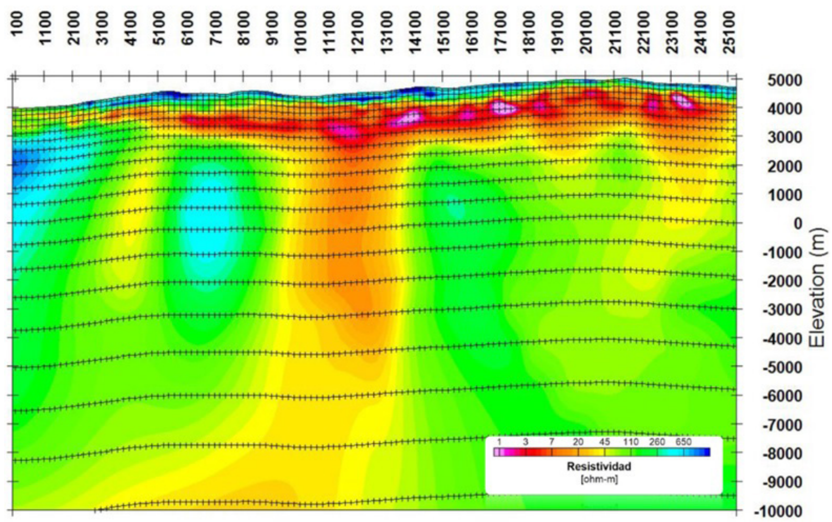


2D Inversion Resistivity Section of Magneto-Telluric (MT) data cut to a depth of 3km through the centre of the Atlantida Cu-Au Porphyry, with conductive shell from the broad 1km grid of MT

CONTIGUOUS E-FIELD ("EMAP"-STYLE) MT

The "EMAP"-style array is used to provide efficient contiguous E-field acquisition along lines which are designed to cross-cut the expected geological structure. H-field acquisition is usually "sparse" with around 5 to 7 contiguous E-fields per H-field site. The basic array setup may be enhanced by the use of orthogonal pairs of H-fields which permit the evaluation of the influence of the Hx-field through a non-zero Zxx component to the measured Ex-field which otherwise may bias the estimation of the Zxy component of impedance. Furthermore, occasional orthogonal E-field sites may be used to obtain a subset of tensor impedance information for evaluation of dimensionality or enhancement of inversion modelling.

2D inversion model resistivity section across the Aucanquilcha volcanic complex in northern Chile. Imaging of resistivity contrasts associated with near surface hydrothermal activity and deep central magma chamber and peripheral vents.



CSEM (CONTROLLED SOURCE ELECTROMAGNETICS)MT

Although still a relatively underused geophysical technique for land-based acquisition, and particularly in the mineral exploration space, CSEM provides a bridge between the near-field IP and "DC" resistivity methods and the far-field MT techniques. The use of a controlled source may provide benefit in very noisy environments.

There are again a broad range of array types that may be used, but at its most basic the acquisition requires a distribution of E-field dipoles and H-field sites from which the transfer function for each, independently, is obtained at a set of frequencies (fundamentals and higher harmonics) of transmitter signals through grounded dipoles or ungrounded loops usually located at several sites in and around the area of interest.

The CSEM methodology is conducive to incorporation in the case of Vector/Tensor IP and MT surveys, providing a "3-in-1" approach, simply transmitting a few higher frequency current injections through the installed transmitter dipoles than required for IP only. Synchronous time series acquisition/monitoring of the E- and H-fields and injected current waveform permit the estimation (calculation) of the relevant transfer functions.

CSAMT

Controlled Source Audio-frequency Magneto-Tellurics (CSAMT) is akin to CSEM in that it utilizes E- and H-field measurements and a controlled source to provide data for resistivity mapping, however this is typically achieved by estimation (calculation) of an impedance function rather than independent transfer functions for the E- and H-fields.

Contiguous E-field "EMAP"-style arrays are commonly used, but with gDAS32 acquisition instruments it is usual to only transmit a single frequency at a few hundred Hertz whose harmonics ensure adequate impedance data through the problematic band around 2kHz, with the remainder of the bandwidth utilizing natural source signals permitting the transmitter to be located relatively close to the survey grid and as such requiring only low power for safety reasons whilst extending data to low frequency without concern over transmitter overprint (transition and near-field effects).

TRANSIENT ELECTROMAGNETICS

With a maximum sample rate of 32768Hz (sample interval of 30.5µs) the gDAS32 may be used to acquire full time series TEM data, together with full time series monitoring of the transmitter waveform, which, with the very low internal noise of the system and the capability to bring post-processing filtering and robust stacking methods to bear, provides high quality transient decays to late times. Large effective area dB/dt receiver coils may result in saturation of the time series data during transmitter waveform turn-on and -off but, if required, may be infilled with a second channel acquiring data from a small effective area sensor. Saturation for B-field sensors (SQUID, fluxgate, for example) is not usually an issue.

A gTX controller device may be used to control the output waveform of third party transmitters with an extremely precise GPS-PPS time base for both standard and non-standard waveforms.

To date, most acquisition of TEM data has been with moving loop (in- and coincident-loop) geometries although surface fixed loop surveying would follow a similar methodology.

SUMMARY

gDAS32 instrumentation may be applied to a broad range of geophysical survey methodologies even beyond the scope of those mentioned in this document both as a receiver directly in use by an operator for TEM and CSAMT surveys for example and, where it is particularly well-suited, to surveys with numerous units installed with data acquired in an autonomous and precisely synchronized manner across numerically and/or spatially large arrays of sensors for combined IP, MT and/or CSEM methodologies.

Greater depth of investigation and the need for higher quality data in adverse environments, suitable for multi-dimensional inversion and interpretation, require numerous sensors, high resolution and precisely synchronized broadband time series acquisition units, and extensive arrays. Numerous sensors can only be efficiently read with an autonomous and truly distributed (untethered) acquisition system, and extensive arrays require reliable autonomous functionality and precise synchronization over large areas. Surveys can be designed to leverage these distributed systems according to the targets of interest, as well as the environmental, social and geological setting.