Data processing summary:

WTRMP Helicopter electromagnetic surveys - Dolcoath, Meredith, Mount Read Volcanics and Balfour (2001-2002)

Dundas open-file helicopter electromagnetic survey (1999)

Dr James Reid, School of Earth Sciences, University of Tasmania

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1. Introduction

1.1 WTRMP survey

Approximately 16,000 line km of helicopter electromagnetic (HEM) data were acquired in 2001-2002 as part of the Western Tasmanian Regional Minerals Program (WTRMP). The four survey areas flown were

Dolcoath granite
Meredith granite
Mount Read Volcanics (MRV)
Balfour

HEM data were acquired using a Geotech Hummingbird system, operated by GeoInstruments (January 2001) and Fugro Airborne Surveys (November 2001 – April 2002). The rugged nature of the survey areas unfortunately meant that two birds were irreparably damaged or destroyed during the survey. Typical bird specifications are listed in Table 1. Exact specifications of each survey bird, including the dates of operation, can be found in the TAS_HEM_README file included with the raw HEM data files. A copy of the relevant section of this file is included as Appendix 1 of this report. Nominal bird height for the survey was 30 m – actual bird heights are often greater than this due to the rugged and heavily-forested terrain. Flight line spacing was 200 m, with tie lines spaced at 1500 m. Flight line direction was east-west for the Meredith, MRV and Balfour survey blocks, and north-south for Dolcoath.

Frequency (Hz)	Geometry	Separation (m)	Max. depth of penetration (m)
34,000	HCP	4.79	110
7,000	VCX	6.25	80
6,600	HCP	6.25	150
980	VCX	6.03	80
880	HCP	6.03	145

Table 1. Typical parameters of Hummingbird HEM systems used for the WTRMP survey. HCP = horizontal coplanar, VCX = vertical coaxial. Estimated depth of penetration is discussed in Section 1.4 of the text.

1.2 Dundas survey

The Dundas HEM survey was commissioned by Pasminco Exploration, and was flown in March 1999. Data were acquired using a Geotech Hummingbird system, operated by GeoInstruments. Actual transmitter-receiver separations for each coil pair were not supplied by the contractor, and separations typical of a 1999-vintage Hummingbird system have been assumed in data processing. Nominal system specifications for the Dundas survey are listed in Table 2.

Frequency (Hz)	Geometry	Separation (m)	Max. depth of penetration (m)
34,000	HCP	5.1	115
7,000	VCX	6.29	80
6,600	HCP	6.29	150
980	VCX	6.03	85
385	HCP	6.03	145

Table 2. Parameters of Hummingbird HEM systems used for the Dundas survey. HCP = horizontal coplanar, VCX = vertical coaxial.

1.3 Data conventions

WTRMP

Raw data delivered by the contractors consists of levelled secondary inphase and quadrature data at each frequency. By convention, inphase and quadrature Hummingbird HEM responses over purely-conductive (i.e., non-magnetic) earths are expected to be positive for the HCP geometry, and negative for VCX. However, the effects of noise, levelling errors, or magnetic polarization (Huang and Fraser, 2000), can cause either (or both) the inphase or quadrature responses at a particular frequency to be opposite in sign to those expected from a conductive earth. Magnetic polarisation affects the inphase response more strongly than the quadrature response, and is most pronounced at the lower frequencies. Strong magnetic polarisation can be readily identified where negative low-frequency inphase responses are coincident with large total field magnetic anomalies.

Dundas

The 1999 Dundas HEM data file assumes a different sign convention to that for the WTRMP data. Over a purely-conductive earth, HCP *and* VCX data are assumed to be positive.

1.4 Estimated depth of penetration

Approximate depths of penetration for each survey have been determined using the method of Peltoniemi (1998), and are listed in Tables 1 and 2. These depths of penetration are based on the inductive-limit response of a homogeneous half-space, and have been calculated assuming a bird height of 30 m and a nominal noise level of 2.5 ppm. The depth of penetration is the depth at which the half-space inductive-limit response falls below four times the assumed noise level (i.e., 10 ppm). Note that at the inductive limit (corresponding to the case of a perfectly-conductive half-space or/and infinite frequency), the response is independent of frequency, and depends only on the coil separation and geometry.

The nominal bird height of 30 m has been subtracted from the depths given in Tables 1 and 2, so that they represent depths of investigation below the surface of the earth. Bird heights greater than 30 m will reduce the effective penetration depth e.g., for a bird height of 50 m (20 m higher than the nominal bird height of 30 m) depths of penetration listed in Table 1 by should be reduced by 20 m etc. The maximum depth of penetration for the survey is estimated at ~150 m. This is reasonably consistent with maximum depths of around 180 m obtained by conductivity-depth transformation of the data (see Section 2).

1.5 Data quality

Resistivities within the WTRMP and Dundas survey areas are high, typically ranging between and few-hundred to a few thousand Ωm. These high resistivities have generally resulted in very low signal strengths at 385 Hz, 880 Hz and 980 Hz, although strong responses are observed at these frequencies over conductive lithologies such as Tertiary basalts and carbonaceous shales.

The primary quality control for the WTRMP survey was a daily repeat test flight line. The location of the test flight for each survey area was chosen by the contractor in order that test flights would cause minimum inconvenience to production surveying. A different test line was flown in each survey area, and test line lengths ranged from < 1 km to ~ 4 km. Test flight data have been used to assess the general repeatability of HEM data acquired on different days (or using different birds) during the survey. Assessment of noise levels for the survey based on the test flight data has been complicated by large 'DC shifts' or biases in the measured inphase and quadrature responses from individual flights. An analysis of system noise will be the subject of a future report.

One data quality issue identified via analysis of test flight and production data has been a negative inphase response of up to ~10 ppm at 880 Hz in data acquired over resistive, nonmagnetic lithologies (D'Andrea, 2001, Griggs, 2002). The source of this coherent negative response has not been established: a number of possible sources of levelling errors in HEM data are discussed by Huang and Fraser (1999). Additional levelling of the WTRMP data would be required to remove the negative 880 Hz inphase response, and to improve the quantitative interpretation of the data.

No additional quality control procedures were carried out for the Dundas survey, other than the daily phasing and gain checks normally carried out by the contractor.

2. Conductivity-depth transformation

Levelled inphase and quadrature HEM data from both flight and tie lines have been transformed to conductivity vs. depth using EMFlow v3.2 (Macnae et al., 1991, 1998). Sengpiel sections (Sengpiel, 1988) have also been computed for the WTRMP surveys. Code for the Sengpiel conductivity-depth transformation was written by Dr. J. Reid. It should be noted that both the EMFlow and Sengpiel data transformations are based on one-dimensional models. Both methods therefore give a reasonable approximation to the actual distribution of conductivity with depth whenever the earth is locally layered or quasi-layered, but can produce erroneous results or artefacts over steeply-dipping or multi-dimensional structures.

Neither the EMFlow or Sengpiel transformations account for the effects of magnetic polarisation on the HEM response (Huang and Fraser, 2000). The HEM response is only affected by the magnetic susceptibility of the earth within the depth of investigation of the system (i.e., the upper 150-180 m) and conductivity-depth data from areas with shallow magnetic sources should be regarded as unreliable. Magnetic polarisation can be identified by comparison of the raw inphase and quadrature HEM data with magnetometer (TMI) data - very strong magnetic polarisation will cause the inphase response at the lowest frequency to be strongly negative.

A summary of processing using the EMFlow and Sengpiel algorithms is given below:

2.1 EMFlow conductivity-depth images (CDIs)

The EMFlow algorithm is complex, and is described in detail by Macnae et al. (1991, 1998). EMFlow processing followed the procedures for HEM data outlined in Macnae (2001). Important EMFlow processing options are described in the file "EMFlow_processing_notes.txt" included with the digital CDI data.

The levelled HEM data files from Dolcoath, Meredith and Mount Read Volcanics were found to contain some incorrect helicopter radar altimeter (radalt) readings, presumably due to returns from the tree canopy in heavily forested parts of the survey area. The bird is suspended 30 m below the helicopter, and helicopter radalt readings < 30 m therefore correspond to bird positions below the surface. The presence of such radalt readings in the data file was found to cause the EMFlow CDI process to terminate prematurely. As a consequence, data points corresponding radalt < 31 m were deleted from the raw data prior to EMFlow processing. Affected sections of data are listed in the files "meredith_neg_alts.txt", "dolcoath_neg_alts.txt" and "mrv_neg_alts.txt" included with the CDI data. No negative bird altitudes were encountered in the Balfour or Dundas data sets.

2.2 Sengpiel sections

The Sengpiel conductivity-depth transformation has been described by Sengpiel (1988) and Sengpiel and Siemon (2000). The method involves transformation of raw HCP and VCX inphase and quadrature data first to apparent conductivity (σ_a), and subsequent calculation of a "centroid depth" (z_p*) from the apparent conductivity data at each frequency.

Apparent conductivity is calculated using the "inphase-quad" algorithm (Fraser, 1978), and as such is not affected by errors in the measured radar altitude due to a dense tree canopy. The inphase-quad algorithm also yields an apparent height of the EM bird above the halfspace, D_a.

The centroid depth at each frequency is given by

$$z_p^{\ *} = (D_a - h) + \frac{\sqrt{2/\sigma_a \omega \mu_0}}{2} \qquad (1)$$

where

$\omega = 2\pi f$
f = frequency
σ_a = apparent conductivity at frequency f (from inphase-quad algorithm)
μ_0 = magnetic permeability of free space
D_a is apparent height (from inphase-quad algorithm)
h is the height of the bird above the surface, measured by the radar altimeter.

Because the centroid depth calculated using (1) depends on the bird altitude h, it can therefore be affected by radar altimeter errors. During processing of the WTRMP data, negative (i.e. above surface) centroid depths were sometimes observed. These negative depths were found to correspond to erratic radar altimeter readings (spikes), and have been deleted from the final Sengpiel conductivity-depth data.

The final result of Sengpiel conductivity-depth transformation is a (σ_a,z_p*) pair for each frequency. A maximum of five conductivity-depth pairs are computed at each fiducial. In areas of poor data quality, it may not be possible to calculate (σ_a,z_p*) at some frequencies. The inphase-quad algorithm used to determine apparent conductivity is valid only if the observed responses are consistent with a purely-conductive earth (see Section 1.3 above).

Accordingly, no conductivities are calculated in areas of poor signal (where noise can result in a sign change in the response), or where data are affected by levelling errors or strong magnetic polarisation. In some of the resistive areas covered by the WTRMP survey (e.g., Meredith granite), it was only possible to calculate (σ_a,z_p*) at the highest frequency.

It is well established in the HEM literature that Sengpiel sections tend to underestimate the depth to a conductive layer (Huang and Fraser, 1996; Sengpiel and Siemon, 2000). Furthermore, Sengpiel apparent conductivities and centroid depths calculated at similar frequencies (e.g. 7000/6600 Hz and 980/880 Hz) are generally very similar (e.g. Table 3). This means that the Sengpiel transformation effectively yields only three (apparent conductivity, centroid depth) pairs at each location.

Despite these disadvantages, Sengpiel sections are very useful for a preliminary appraisal of data quality, and also as a check on conductivities and depths calculated using EMFlow.

Frequency (Hz)	Geometry	Centroid depth (m)	Apparent conductivity (S/m)
34,000	HCP	14.68	0.01812
7,000	VCX	23.51	0.05687
6,600	HCP	23.88	0.05808
980	VCX	43.70	0.04429
880	HCP	46.14	0.04253

Table 3. Sengpiel apparent conductivity and centroid depth computed for a theoretical three-layered model. Upper layer has conductivity 0.01 S/m and thickness 20 m, and the middle layer has conductivity 0.1 S/m and thickness 25 m. Basement conductivity is 0.001 S/m and bird height is 30 m.

Noise cutoff

In initial processing of the WTRMP data, it was found that responses below the nominal noise level of the system (2.5 ppm) often produced unwanted artifacts in the Sengpiel sections. Accordingly, a noise cutoff of 2.5 ppm was used for processing of the entire survey – if *either* the inphase or quadrature response is less than 2.5 ppm at a given frequency, then no apparent conductivity is computed.

An example of EMFlow CDI and Sengpiel sections from Meredith survey area is shown in Figure 1. The transformations yield broadly similar conductivities and depths. Areas on the Sengpiel section where only very shallow conductivities have been computed (or none at all) correspond to areas of poor data quality, particularly at the lower frequencies. Deep conductivities computed in these areas by EMFlow should be treated with caution.

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Appendix 1 WTRMP HEM Survey specifications

Area A:	Dolcoath
Survey flown:	January 2001 - April 2002
Traverse line spacing:	200 metres
Traverse line direction:	000 / 180 degrees
Tie line spacing:	2000 metres approx
Tie line direction:	090 / 270 degrees approx
Survey height:	EM towed Bird at 30m agl
Area B.C,D:	Meredith,Mt Read Volcanics, Balfour
Survey flown:	January 2001 - April 2002
Traverse line spacing:	200 metres
Traverse line direction:	090 / 270 degrees
Tie line spacing:	2000 metres approx
Tie line direction:	000 / 180 degrees
Survey height:	EM towed Bird at 30m agl
Electromagnetic System	Hummingbird 5 frequency EM system
Resolution:	1ppm
Recording Interval:	0.1 sec (approx. 3.5 metres sampling)
Data acquisition:	Geo Instruments Model G2002 system Geotech Hummingbird system
Aircraft:	AeroSpatiale Squirrel helicopter AS350BA
MAGNETOMETER	
Type:	Geometrics G822A Caesium vapour
Resolution:	0.001 nT
Recording interval:	0.1 sec (approx. 3.5 metres sampling)
Installation:	Magnetometer sensor mounted in HEM bird.
NAVIGATION	
Flight path navigation:	Real time satellite Differential GPS system
Navigation equipment:	Fugro OMNISTAR GPS receivers
Flight path record:	WGS84 Easting/ Northing coordinates
Radar altimeter:	Collins Alt50
GPS base station locations:	Fugro OMNISTAR(Real Time DGPS)

HUMMINGBIRD COIL SPECIFICATIONS:

Bird 1 - Between Julian day 31, 2001 to day 44, 2001

Channel :	1	2	3	4	5
Freq (Hz) :	7000	6600	980	880	34000
Orientation :	CX	CP	CX	CP	CP
Coil Separation (m) :	6.26	6.26	6.01	6.01	4.93

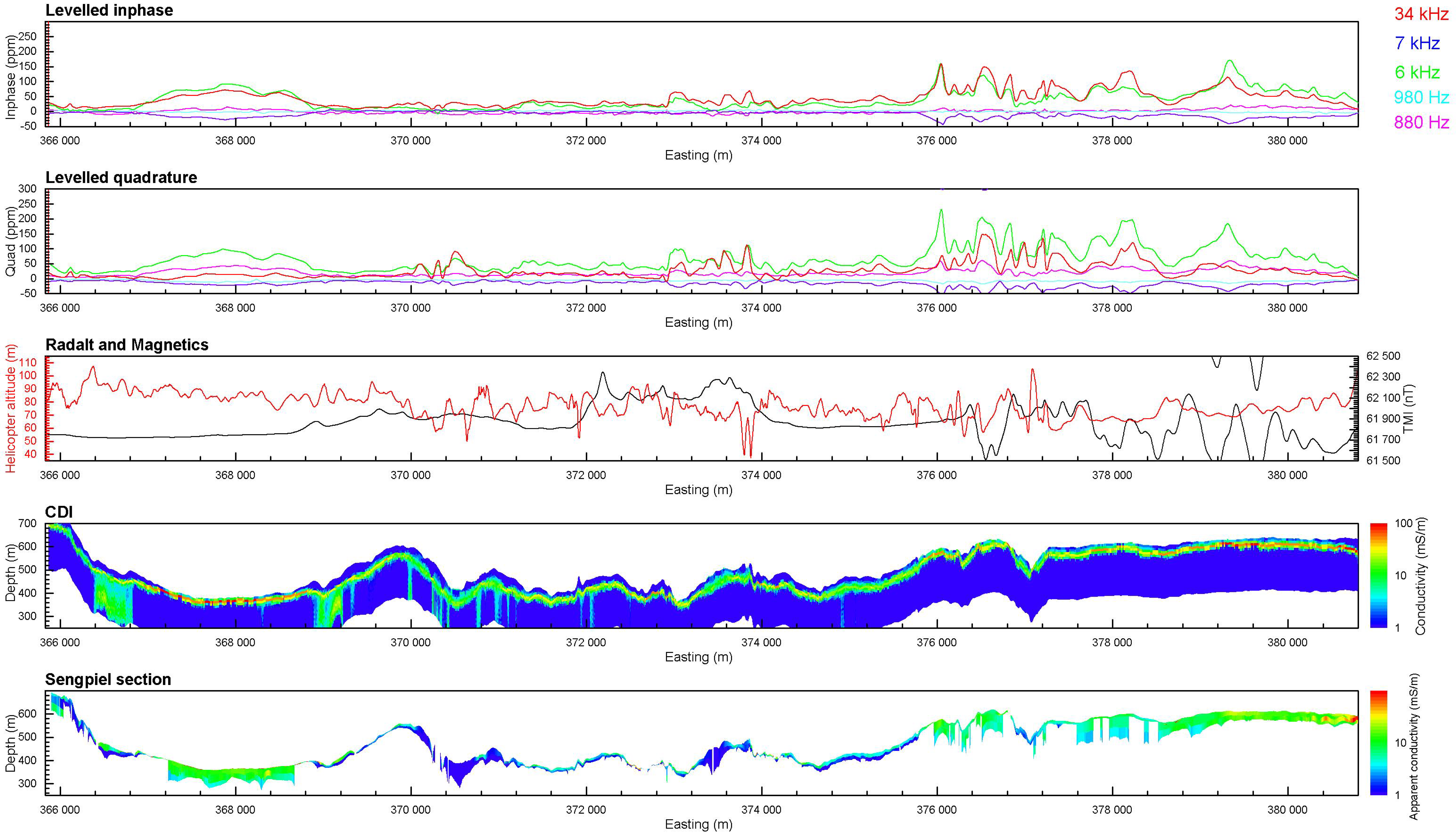
Bird 2 - Between Julian day 310, 2001 Flight 1 to day 67, 2002, Flight 93

Channel :	1	2	3	4	5
Freq (Hz) :	7000	6600	980	880	34000
Orientation :	CX	CP	CX	CP	CP
Coil Separation (m) :	6.26	6.26	6.01	6.01	4.93

Bird 3 - After Julian day 67, 2002, Flight 94 onwards

Channel :	1	2	3	4	5
Freq (Hz) :	7000	6600	980	880	34000
Orientation :	CX	CP	CX	CP	CP
Coil Separation (m) :	6.25	6.25	6.03	6.03	4.79

Figure 1



WTRMP Hummingbird HEM survey
Meredith Granite
Line 10312

Levelled inphase and quadrature data
Radalt/Magnetics
EMFlow v3.2 CDI
Sengpiel section

Project: An electromagnetic interpretation of west and north-west Tasmania

Coordinates: AGD66/TMAMG Zone 55

Date 3/12/02

Scale 1 : 47608

0m 1000m 2000m