A Novel Semi-airborne EM System for Mineral Exploration
First Results from Combined Fluxgate and Induction Coil Data


Semi-Airborne Electromagnetics

- Grounded electrical dipole source with 1-2 km length
- Measure magnetic field (variations) in the air
- Accurate motion sensors to correct for related noise
- Frequency domain processing (similar to CSEM)
- 3D modeling and inversion of the data
Measurement System

Christian Nittinger
## System Specifications

<table>
<thead>
<tr>
<th></th>
<th>Fluxgate</th>
<th>Coils</th>
<th>Potassium Mag.</th>
<th>INS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>mag. field variations (Bx, By, Bz)</td>
<td>oblique mag. field variations (Bu, Bv, Bw)</td>
<td>magnetic total field intensity (Btot)</td>
<td>Position Orientation Acceleration Angular Vel.</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>16384 Hz</td>
<td>16384 Hz</td>
<td>20 Hz</td>
<td>400 Hz</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>&lt; 6 pT rms/Hz @ 1 Hz</td>
<td>0.5 fT rms/Hz @ 1000 Hz</td>
<td>0.3 pT @ 1 Hz (abs. +/- 0.05 nT)</td>
<td>Attitude &lt; 0.01° Drift: &lt; 0.01°/hr</td>
</tr>
</tbody>
</table>

Flight Velocity: ca. 60 kts // 115 km/h  
Flight Height: 42m below helicopter and 50-60 m above topography  
System Weight: ca. 300kg

## Processing Scheme

- **Fluxgate**  
  - Calibration  
  - Rotate to orthogonal  
  - Prediction

- **Coils**  
  - Calibration  
  - Rotate to geo-x,y,z

- **INS**  
  - Noise Prediction  
  - Static Total Field Btot

**Transfer function**  
\[ T(\omega) = B(\omega)/I(\omega) \]

**Instrument Response functions**

**Static Magnetic Field B_{tot}**

- Pitch Axis  
- Roll Axis  
- Tilt Axis
**Processing Scheme**

Noise Prediction in Bird fixed coordinates:
- Predict Noise with Static Field $\mathbf{B}_{\text{tot}}$, IMU Data $\mathbf{R}_T(t)$ and instrument response $\mathbf{C}(t)$
  $$\mathbf{B}_{\text{pred}}(t) = \mathbf{C}(t) \ast \mathbf{R}_T(t) \mathbf{B}_{\text{tot}}$$
- Procrustes Analysis to avoid misalignment Errors of the Prediction:
  $$\mathbf{B}_{\text{cal}}(t) = s \mathbf{B}_{\text{pred}}(t) \mathbf{T} + c$$
  $$\mathbf{B}_{\text{cor,bird}}(t) = \mathbf{B}_{\text{obs,bird}}(t) - \mathbf{B}_{\text{cal}}(t)$$

**Flight Experiment**

- Measurement Area of 4x4 km
- 1km dipole length
- 10.41 Hz, 20A, rectangular source signal
- 25 flight lines above three source positions
- Previous Measurements: ERT, HEM, LOTEM, ...
Flight Experiment

- Measurement Area of 4x4 km
- 1km dipole length
- 10.41 Hz, 20A, rectangular source signal
- 25 flight lines above three source positions
- Previous Measurements: ERT, HEM, LOTEM, ...

Data Processing – Raw Data vs. Predicted Data (Fluxgate)
Data Processing

- B\textsubscript{z} Component in nT (after Deconvolution)
- 10Hz high-pass filtered for visualization
- Processing Scheme helps to correct for high-frequency noise as likely as for low-frequency noise
Data Processing – Source current vs. measured signal

- 20A current
- Clean signal from source current in the time series data

Data Processing – Spectra Comparison IMU vs. Mag. Field
Data Processing – Transfer Functions $T_z(\omega) = \frac{B_z(\omega)}{I(\omega)}$

Data Processing – Imaginary Part of $T_z(\omega)$
Data Processing – Imaginary Part of Tz(ω)

Fluxgate: 614.5834 Hz

Coil: 614.5834 Hz

Data Processing (5) – Pseudosections of a flight line

Christian Nittinger

Nittinger et al., A Novel Semi-airborne EM System for Mineral Exploration
Modeling Results

- 3D inversion model compares well to ground-based ERT Model

More at EMTF Contribution:
3D Inversion of the Semi-airborne Electromagnetic Data from Germany
M. Cherevatova et al.

Conclusions

- Frequency domain airborne system with a range of 1Hz-10kHz
  → grounded source 10.41 Hz, choose freqs. that avoid noise peaks (motion/anthropogenic)
- Beneficial combination of Fluxgate, Coil and IMU (+ TMI in next flights)
- Inflight system noise < 50pT/sqrt(Hz) at frequencies 10-400Hz
  and < 1pT/sqrt(Hz) at frequencies > 400Hz
- Calibration/processing + data quality can potentially be further improved
  → induced voltages in induction coils not yet considered
- Flight area of ca. 4x4km, can be increased by the use of two simultaneous sources
Acknowledgements

* DESMEX Working Group Members

WWU, Münster - Michael Becken, Maria Cheruvatova, Christian Nittinger
BGR, Hannover - Tina Martin, Stephan Costabel, Hauke Petersen, Annika Steuer, Ursula Noell, Uwe Meyer, Bernhard Siemon
Metronix, Braunschweig - Bernhard Friedrichs, Ulrich Matzander
LIAG, Hannover - Raphael Rochlitz, Thomas Günter
IPHT, Jena - Markus Schiffler, Andreas Chwala, Ronny Stolz
IGM, Köln - Wiebke Möhrle, Pritam Yogeshwar, Cai Ji, Bülent Tezkan
TUBAF, Freiberg - Patrick Krolop, Thomas Seifert
Supracon, Jena - Marco Schulz, Viatscheslav Zakosarenko, Nikolay Ukhansky, Jens Kobow

Thanks to all Technicians, Engineers, Co-Workers and Students for the help during the field work!