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Tie-line corrections for semi-airborne EM and airborne magnetic data

Summary

Airborne responses at cross-over points of lines and tie-lines should be identical. Differences may occur due to different flight height or due to a drift in the data or the recording instrument. For airborne magnetic surveying, we formulate an inverse problem to recover variations in the background field by matching data at cross-over points. The estimated drift function resembles observatory recordings of diurnal variations. For semi-airborne EM data, we formulate an inverse problem to recover synchronization errors that occurred because of loss of GPS lock.

Recovery of synchronization errors in semi-airborne EM surveys

A false setting of the GPS module of the airborne receiver resulted in repeated losses of GPS lock and ultimately in accumulated synchronization errors of airborne EM and source current recordings. Consequently, phase shifts are evident in the estimated transfer functions. Relative lag times can be reconstructed by matching the phase of transfer functions at crossover points. Absolute time calibration is done at transmitter overflight time windows or by comparison to reference station station.

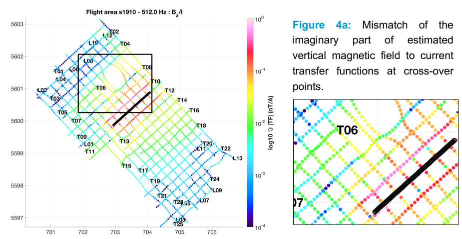

Figure 4a: Mismatch of the imaginary part of estimated vertical magnetic field to current transfer functions at cross-over points.

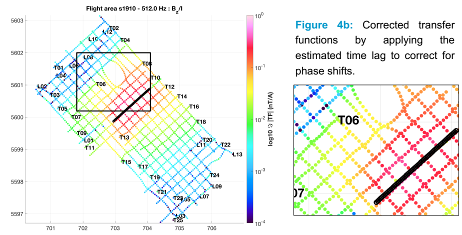

Figure 4b: Corrected transfer functions by applying the estimated time lag to correct for phase shifts.

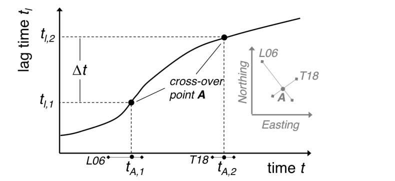

Figure 5a: Schematics of the lag time function. Synchronization errors due to GPS loss of the airborne receiver accumulate as a function of time. Relative time shifts are estimated from cross-over points A, which are passed at times $t_{A,1}$ and $t_{A,2}$, e.g. during overflights along lines L06 and T18 (cf. Inset).

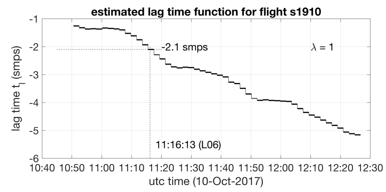

Figure 5b: Estimated lag time function for the data example depicted and Figure 4a. The estimate has been used to correct for phase shifts (Figure 4b).

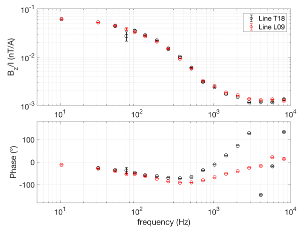

Figure 1: Phase mismatch of a semi-airborne EM transfer function observed at the cross-over point of two flight lines.

Inverse problem formulation:

Denote cross-over point as **A**. Let the relative lag time accumulated between time instances $t_{A,1}$ and $t_{A,2}$ be

$$\Delta t_A = t_{l,2} - t_{l,1}$$ → *Figure 5a*

The phase difference observed at point A should be

$$\Delta\varphi_A = \varphi_{T18,A} - \varphi_{L09,A} = -\omega \Delta t_A$$

Set up an over-determined problem with multiple frequencies

$$\begin{bmatrix} \Delta\varphi_A(\omega_1) \\ \Delta\varphi_A(\omega_2) \\ \vdots \\ \Delta\varphi_A(\omega_N) \end{bmatrix} = \begin{bmatrix} 1/\omega_1 \\ 1/\omega_2 \\ \vdots \\ 1/\omega_N \end{bmatrix} \Delta t_A$$

$$\mathbf{d}^{obs} = \mathbf{G}\Delta t \ ,$$

and solve this in the sense of least squares to obtain

$$\Delta t_A^{est} = [\mathbf{G}^T\mathbf{G}]^{-1}\mathbf{G}^T\mathbf{d}^{obs}$$

The corrected transfer functions are obtained from

$$T_{x,y,z}(\omega) = \widetilde{T}_{x,y,z}(\omega) e^{i\omega\Delta t^{est}}$$ → *Figures 2,3*

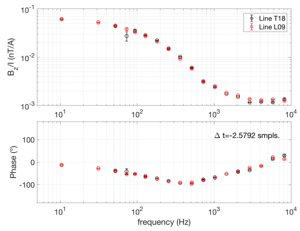

Figure 2: Transfer function corrected for an estimated lag time of -2.58 samples. (f_s=16.384 Hz)

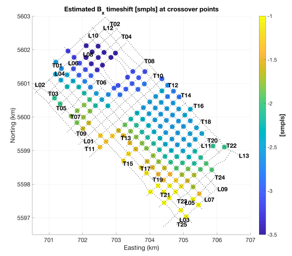

Figure 3: Estimated lag times for all cross-over points.

Collect all lag time estimates and formulate an ill-posed inverse problem to reconstruct a consistent and continuous lag time function. For this purpose, discretize the lag time function as $\mathbf{t}_l(t_i)$ and construct an Operator $\mathbf{G}_l$ such that the observed (estimated from cross-over points) relative lag-times are

$$\Delta\mathbf{t}^{obs} = \mathbf{G}_l\mathbf{t}_l$$

The regularized solution is

$$\mathbf{t}_l^{est} = [\mathbf{G}_l^T\mathbf{G}_l + \lambda\mathbf{W}]^{-1}\mathbf{G}_l^T\Delta\mathbf{t}^{obs}$$ → *Figure 5b*

Recovery of geomagnetic variations

After applying a parametric model for aircraft manoeuvre compensation of TMI data (Leliak, 1961), we still observed discrepancies at cross-over points in the range of a few nT.

We define an ill-posed problem to estimate a drift that matches all observed TMI differences ΔF_A at cross-over points **A**. The procedure retrieves the natural variation of the magnetic field, $F(t)$, and can thus substitute a reference station on the ground.

Collecting all differences in a data vector $\Delta\mathbf{F}^{obs}$, discretizing the time function of magnetic variations as $\mathbf{F}_l$, and constructing an Operator $\mathbf{G}_l^T$ such that the observed (estimated from cross-over points) differences can be predicted as a function of time, the time-dependent estimate of the regularized solution is

$$\mathbf{F}_l^{est} = [\mathbf{G}_l^T\mathbf{G}_\mathbf{l} + \lambda\mathbf{W}]^{-1}\mathbf{G}_l^T\Delta\mathbf{F}_l$$

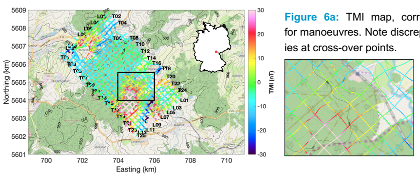

Figure 6a: TMI map, corrected for manoeuvres. Note discrepancies at cross-over points.

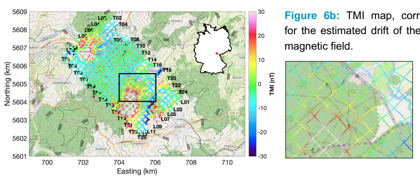

Figure 6b: TMI map, corrected for the estimated drift of the total magnetic field.

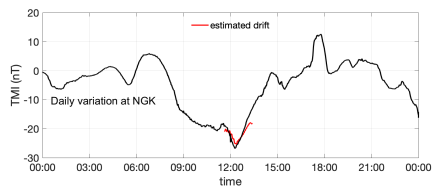

Figure 7: Estimate of magnetic drift as a function of time (red line) that minimizes observed discrepancies at cross-over points. The curve fits the geomagnetic variation of the TMI observed at the geomagnetic Observatory on Niemegk (NGK, black line) for the particular measurement day. The estimate is applied to the data (cf. Figure 6b).

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