Analysis of Ground Current Disturbances at Magnetic Observatories

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Geomagnetic observatories can be significantly affected by local fields produced by underground electric currents, especially at higher frequencies. Therefore, magnetic time series with the new INTERMAGNET 1-Hz sampling rate standard should be considered carefully. Here, we present first results of a systematic investigation of anthropogenic disturbances obtained from the comparison of data from the Cobenzl (WIK) and Conrad (WIC) observatories during their simultaneous operation in February 2016. In addition to magnetic measurements, the horizontal component of the electric field at WIK has been measured with Cu-CuSO$_4$ non-polarizable electrodes. These measurements prove that magnetic field variations at WIK are caused primarily by local underground currents at frequencies above 1 mHz. Due to its location close to the city of Vienna the amplitude of such variations (±3 nT) is unusually high for a magnetic observatory. In other observatories detectable disturbances in the order of ~0.5 nT can be expected in 1-Hz data. Electric field measurements can be potentially used to reduce or eliminate such unwanted contributions.

The relation between the horizontal components of electric and magnetic field variations can be expressed in matrix form by

$$\begin{bmatrix} E_x^* \\ E_y^* \end{bmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \cdot \begin{bmatrix} H_x^* \\ H_y^* \end{bmatrix} \quad (1)$$

where (E_x^*, E_y^*) and (H_x^*, H_y^*) are the Fourier transforms of electric and magnetic time series, and Z_{ij} are the component of the frequency-dependent impedance tensor $\mathbf{Z}(\nu)$. In case of vertically propagating electromagnetic waves, as assumed in magnetotellurics, a homogeneous underground with electric conductivity σ is characterized by $|\mathbf{Z}| \sim (\nu/\sigma)^{1/2}$ with a phase of 45°. On the other hand, a horizontal current sheet with current density J_x yields a real, frequency-independent impedance $Z_{xy} = -2/J_x$. It is therefore possible to discriminate between these two causes of magnetic field variations by analysing the impedance tensor obtained from the solution of eq. (1).

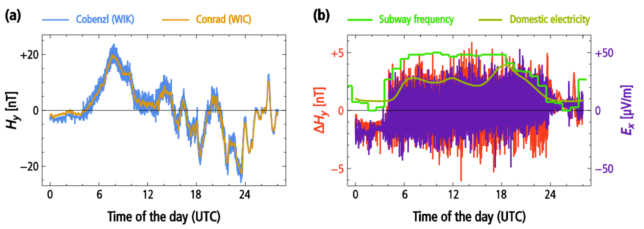

Figure 1: (a) Magnetic field variations of the N-S component measured at the two observatory during February 2-3, 2016. **(b)** Difference between magnetic measurements at the two observatories (ΔH_y red), and E-W electric field measurements at WIK (E_x violet). The scheduled subway frequency and the domestic electricity demand during a working day in winter are shown for comparison, after rescaling them to match the electric and magnetic field variation ranges.

Magnetic measurements with 10 Hz sampling rate have been performed with LEMI-25 fluxgate magnetometers in both observatories. WIK measurements are clearly affected by noise with a diurnal cycle corresponding to electric power consumption in the city of Vienna. This cycle is evident when the WIC record, assumed to represent large-scale natural variations, is subtracted from WIK (Fig. 1). Electric field measurements have been performed with two orthogonal pairs of Cu-CuSO$_4$ non-polarizable electrodes placed at a distance of ~200 m. These measurements are affected by a similar diurnal cycle (Fig. 1).

Counter clockwise rotation of the impedance tensor reconstructed with eq. (1) by ~24° yields a single significant component Z_{xy} with zero phase and nearly constant amplitude in the 1-20 mHz frequency range (Fig. 2). This solution is compatible with a current sheet flowing below the Cobenzl observatory mainly along the E-W direction. No coherent solutions are obtained with WIC magnetic data, demonstrating the inherently local nature of the disturbances. Because of the well-defined proportionality between electric and magnetic field variations, electric field measurements can be potentially used to correct disturbances of magnetic observatory records associated with local underground currents. Further tests are required to validate this possibility.

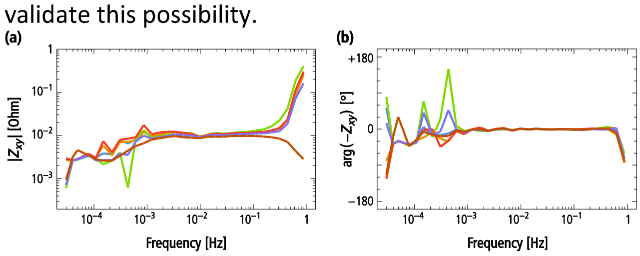

Figure 2: Principal component Z_{xy} of the impedance tensor reconstructed from the electric and magnetic measurements shown in Fig. 1a. **(a)** Amplitude and **(b)** phase of Z_{xy} obtained from six possible solutions of eq. (1).

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