Application of Semi-Airborne Transient Electromagnetic Method in Ancient River Area

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Abstract. Semi-airborne transient electromagnetic method (SATEM) is a new type of transient electromagnetic measurement method. Compared with the ground transient electromagnetic system, the system has the characteristics of convenience, high efficiency, large detection range, repeatable observation, high lateral resolution, etc. At the same time, this ground-space model shows that this method is suitable for detecting missions in mountainous and undulating terrain, and has obvious advantages in dividing underground space structure. In this paper, the theory of semi-airborne transient electromagnetic method is systematically studied and forward modeling is used to simulate the diffusion law of the end value under different resistivity and the characteristics of the response curve under different influencing factors of G model. The identification capability of SATEM for multi-layer model is verified by theoretical inversion, which lays a foundation for the practical application of SATEM in an ancient river channel. Finally, the application of SATEM to an example of an ancient river channel verifies the practicability and efficiency of the method, and the detection results are in good agreement with the local geological data.

1. Introduction
Semi-Airborne Transient Electromagnetic Method (SATEM) is a transient electromagnetic measurement system that uses ground emission and air reception modes [1].

Figure 1. Schematic diagram of working principle of SATEM
The specific content is to use a long grounding conductor as the emitting source to supply a stable current. When the current in the source is turned off, the primary field will disappear with the current at the same time, while the underground conductive geological body will generate induced current under the excitation of the primary pulse. The purpose of detecting the underground geological body is to study the attenuation characteristics of the secondary field generated by the induced current. Since the secondary field is a pure abnormal response, the detection resolution is high [2].

2. Forward Simulation
Considering the construction problems in actual exploration, the receiving coil mainly receives the Hz component of the magnetic field [3]. For long wire source magnetic field vertical components Hz are:

\[
Hz = \frac{1}{4\pi} \int_{-L}^{L} \int_{-R}^{R} \frac{y}{r} e^{i\omega t} \left(1 + \frac{y^2}{2} \right) J_1(\lambda R) d\lambda dR
\]

In the formula:

\[
R = \left[ (x - x')^2 + y^2 \right]^{1/2}
\]

Time-frequency transformation:

\[
V(t) = R_0 - \sum_{r=1}^{21} \varphi_r \text{Re}[R(\omega_r)]
\]

In formula (3), \(\omega_r = 10^{(a_r - 10) t}\), \(R(\omega)\) represents frequency domain impedance; \(R_0\) is zero frequency impedance; \(\varphi_r\) is linear filter coefficient; \(\text{Re}[R(\omega_r)]\) represents \(R(\omega)\) real part; \(V(t)\) is induced electromotive force.

2.1. Law of value diffusion in forward field
In order to verify the accuracy of the forward modeling procedure, using the forward 10 ohm-m mapped the homogeneous half space and 200 ohm-m field values of different time slice. It can be seen from the two section diagrams that the electromagnetic field has a slow diffusion speed but a fast field value attenuation in the low-resistance geological body, and a slow field value attenuation in the high-resistance geological body, which is consistent with the smoke ring theory of Nabighian and verifies the accuracy of the forward program.

![Figure 2. 10 Ω theory forward slicing](image1)

![Figure 3. 200 Ω theory forward slicing](image2)

2.2. Response Curve Characteristics under Different Factors
Considering the actual working conditions of the target area, and in order to successfully complete the field work, the theoretical forward modeling is used to simulate the actual situation, and the specific current size, coil height, optimal offset and line source length in the actual work are determined.
According to the known working area, G forward model is set to simulate the actual situation. The following four figures correspond to the attenuation curves of different current intensity, line source length, coil height and offset.

For the detection in the work area, the corresponding data is the shallow stratum data, that is, the early channel information of high frequency. Through forward simulation, the parameters guiding the actual work are obtained. The parameter information is as follows:

- It can be concluded from Fig 4 that for every 5A increase in current, the response value increases by 1 times, and the SNR is higher. Therefore, the current should be as large as possible in the actual project. In this work, the working current is taken as 20A.

- It can be seen from Fig 5 that in the early channel, with the increase in the length of the line source, the response value first increases and then decreases. In order to obtain a higher SNR and at the same time to consider the situation in the field, the length of the line source is determined to be 2000m.

- From Fig 6, we find that the lower the height of the receiving coil is, the higher the SNR is. Within the range allowed by the terrain, the height of the coil is determined to be 50m.

- It can be seen from Fig 7 that, in the early channel, with the increase of the offset, the response value first increases and then decreases. In order to obtain a better SNR, the offset is increased by 100m at the same distance according to the actual situation.
2.3. Inversion Simulation

Its total objective function can be summed up as follows:

$$\phi(m) = \phi_d(m) + \lambda \phi_m(m)$$  \hspace{1cm} (4)

The objective function of observed data in the overall objective function $\phi_d(m)$ can be expressed as:

$$\phi_d(m) = \|W_d(\Delta d)\|^2 = \|W_d(d - F(m) - Jm)\|^2$$  \hspace{1cm} (5)

The termination condition of inversion is judged by root mean square error (RMS), which is defined as:

$$\text{RMS} = \sqrt{\frac{\sum_{i=1}^{N}(d_{i,\text{obs}} - d_{i,fwd}^{obs})^2}{N}}$$  \hspace{1cm} (6)

When the inversion fitting difference is less than the given or the inversion iteration reaches the maximum number of iterations, the inversion is terminated to obtain a locally optimal inversion model [4].

In order to verify the correctness of the inversion program, four models are used for inversion simulation. Model parameters are shown in Table 1.

| Model | Resistivity (Ω·m) | Layer thickness (m) |
|-------|-----------------|--------------------|
| D     | 200/50          | 20                 |
| G     | 50/200          | 30                 |
| H     | 200/80/300      | 20/30              |
| HK    | 300/80/400/200  | 50/50/80           |

**Table 1** model and parameters

![Figure 8. D model theoretical inversion results](image)

![Figure 9. G model theoretical inversion results](image)
It can be found that with the increase of iteration times, the higher the fitting degree, the more accurate the inversion value. In addition, compared with the high resistivity layer, SATEM is better at identifying the low resistivity layer. Therefore, the inversion method can accurately reflect the resistivity difference under different burial depths in the palaeo-channel region.

2.4. Application example

SATEM in ancient river channel adopts TXU-30 transmission system, with 20KW transmission power. Set various parameters as follows: Transmitting fundamental frequency 25Hz; The UAV’s flight speed is 2.5m/s. The effective area of the receiving coil is 1055m²; 50m above the ground. The current size is 20A; Line source length 2200m; The offset distance from each line to the line source is increased by 100m, the layout of survey line is shown in the figure below.

After SATEM data processing, the profile data are output, and then the apparent resistivity inversion graph is obtained through inversion. Fig 13 shows the apparent resistivity inversion diagram with topography (the ratio of horizontal and vertical coordinates is 6:1). It can be seen that the horizontal resolution and vertical continuity of SATEM are well maintained, showing high resistivity at both ends of the survey line and at a slightly higher elevation in the middle, and relatively low resistivity in the channel. The overall resistivity is symmetrically distributed in the middle, and presents a high-low-high-low resistivity feature in the transverse direction.
Figure 13. Apparent resistivity inversion results of survey line 7 and line 8

Figure 14. Inference map of geological interpretation

Through the comparison with local geological data (Fig 14), the good coincidence verifies the practicability of SATEM in the area of ancient river channel.
3. Conclusions
In this paper, the diffusion law of the end value of different resistivity is analyzed by the SATEM method. The response curve characteristics of different influencing factors are also simulated to provide theoretical basis for field construction. Four geoelectric models are used to discuss the ability of regularized adaptive inversion to identify resistivity at different buried depths, which lays a foundation for the interpretation and application of SATEM. Through the application examples of ancient river channels, it can be found that SATEM has the characteristics of convenience, quickness and good horizontal resolution, and has advantages in dividing underground space structure. It is suitable for the application in lakes, marshes, ancient river channels and other places where the traditional geophysical exploration methods are difficult to work, and has good economic and social benefits.

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