NOVEL HIGH RESOLUTION GEOPHYSICAL TECHNOLOGY FOR EXPLORING HIGH LATITUDE ARCTIC REGIONS USING DRIFTING ICE FLOES

The most recent USGS estimates for yet to find (YTF) in the Arctic represent nearly 25% of the world's remaining undiscovered hydrocarbon resources. Of this potential, 84% is thought to exist in the offshore regions (Rice at al, 2013). The seismic method, which is traditionally the leading geophysical technique in the hydrocarbon exploration, encounters tremendous difficulties in the acquisition of the data in the Arctic. In addition to the well known extreme weather conditions, the acquisition of the marine seismic data is further complicated by the existence of unpredictable and varying ice concentrations and coverage, which shorten the time window for conventional seismic operations during the already short open-water seasons. Similar problems exist in the potential application of the controlled source electromagnetic (CSEM) method, which became during the last decade the most promising and successful non-seismic technique in the offshore hydrocarbon exploration (Constable, 2006). In fact, the application of CSEM in the Arctic is even more complicated than that of the seismic method because the transmitter and the receiver antennae (electric dipoles) in CSEM must be located close to the sea floor. Otherwise, due to the so called air wave effect, measured signals consist of a very little information regarding sub-seafloor targets.

The very tempting alternative to the open-water marine geophysical surveys in the Arctic is the use of drift ice for equipment layout and conducting the measurements as it has been realized in the Soviet and Russian north polar (NP, or СП in Russian) ice stations starting from 1937 to now days (e.g. Romanov et al., 1997). Despite very hard weather conditions, these stations operate almost all year around, besides a short summer period, during which the drifting ice floe with the polar station on it, might shrunk below permissible limits. During the operating period, the ice floe travels along a winding path to distances of several (normally from 2 to 5) thousand line kilometers. An example of the travel path of the last ice station, NP-40, is shown in Figure 1.

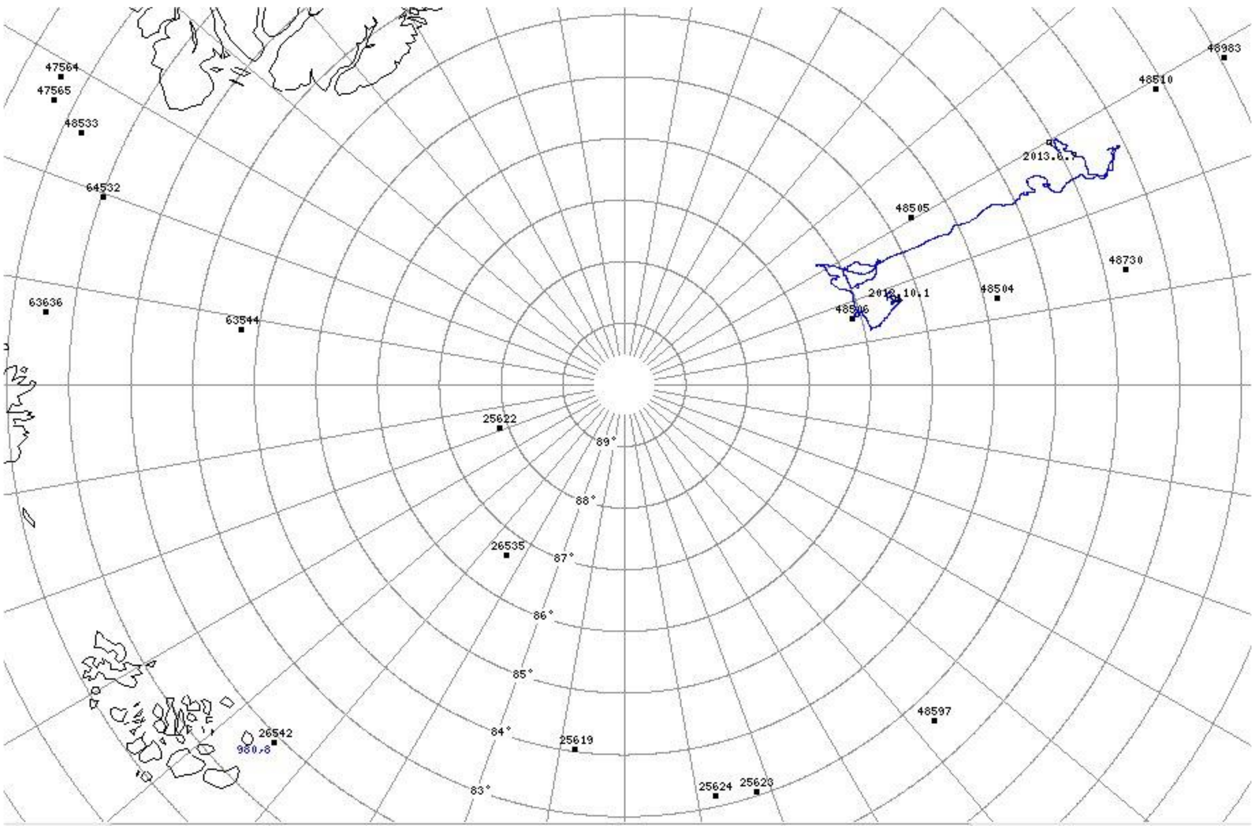

Figure 1. The travel path of the last polar station, NP-40, during the period from October 2012 to June 2013. A total length of the path is 1736 km.

Most of the geophysical measurements in all 40 ice stations were carried out on the ice surface using natural source methods such as gravity, magnetics and magnetotellurics (MT). From the exploration point of view, these methods provide rather limited detectability and resolution and thus can be applied in general reconnaissance surveys only.

We propose a novel high resolution geoelectromagnetic technology using the recently developed EM method based on the use of a very special transmitter antenna called CED-circular electric dipole. The method was first introduced and theoretically substantiated by Mogilatov (1992) and further developed and practically realized by Mogilatov and Balashov (1996). The method comprises the entirely new source of the primary field which includes a central electrode connected to one pole of a generator and (theoretically) a continuum of electrodes located along a circle and connected to another pole (Figure 2). Of course, in practice, the number of outer electrodes is finite, and in most cases, adequately represents the ideal CED if the number of the outer electrodes ≥ 8 (Mogilatov and Balashov 1996).

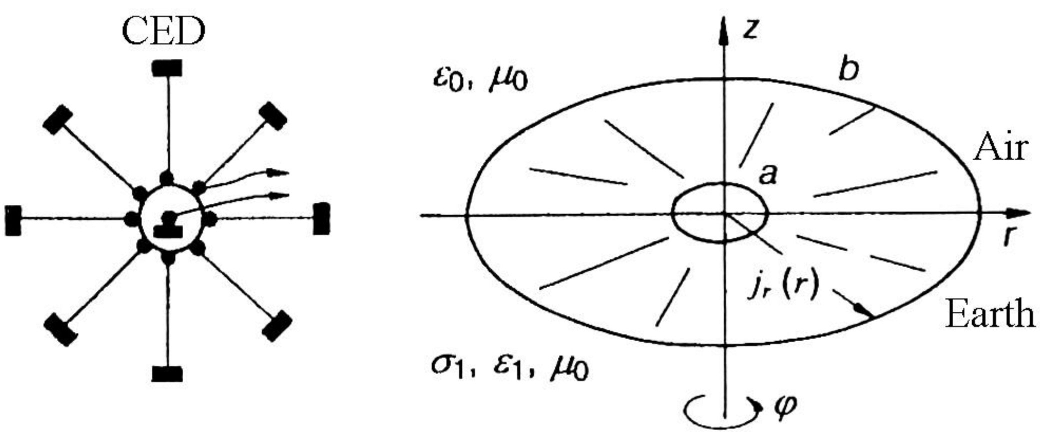

Figure 2. The "real" (left) and the "ideal" (right) circular electric dipoles comprising two concentric electrode systems discretely or continuously distributed along the circles of radius a (the inner or central electrode(s)) and b (the outer electrode(s)) respectively.

Theoretically, CED represents a surface analog of a vertical electric dipole (VED) transmitter, which provides very high sensitivity to thin resistive targets such as hydrocarbon reservoirs, gas hydrates, fresh water, etc. (e.g. Goldman et al., 2013). Unfortunately, the VED method is widely used neither on land nor in sea due to tremendous difficulties in achieving the required strict verticality in boreholes and in water, respectively. Assembling CED both on land (Figure 3) and offshore (Figure 4) is significantly simpler and more accurate than that of VED.

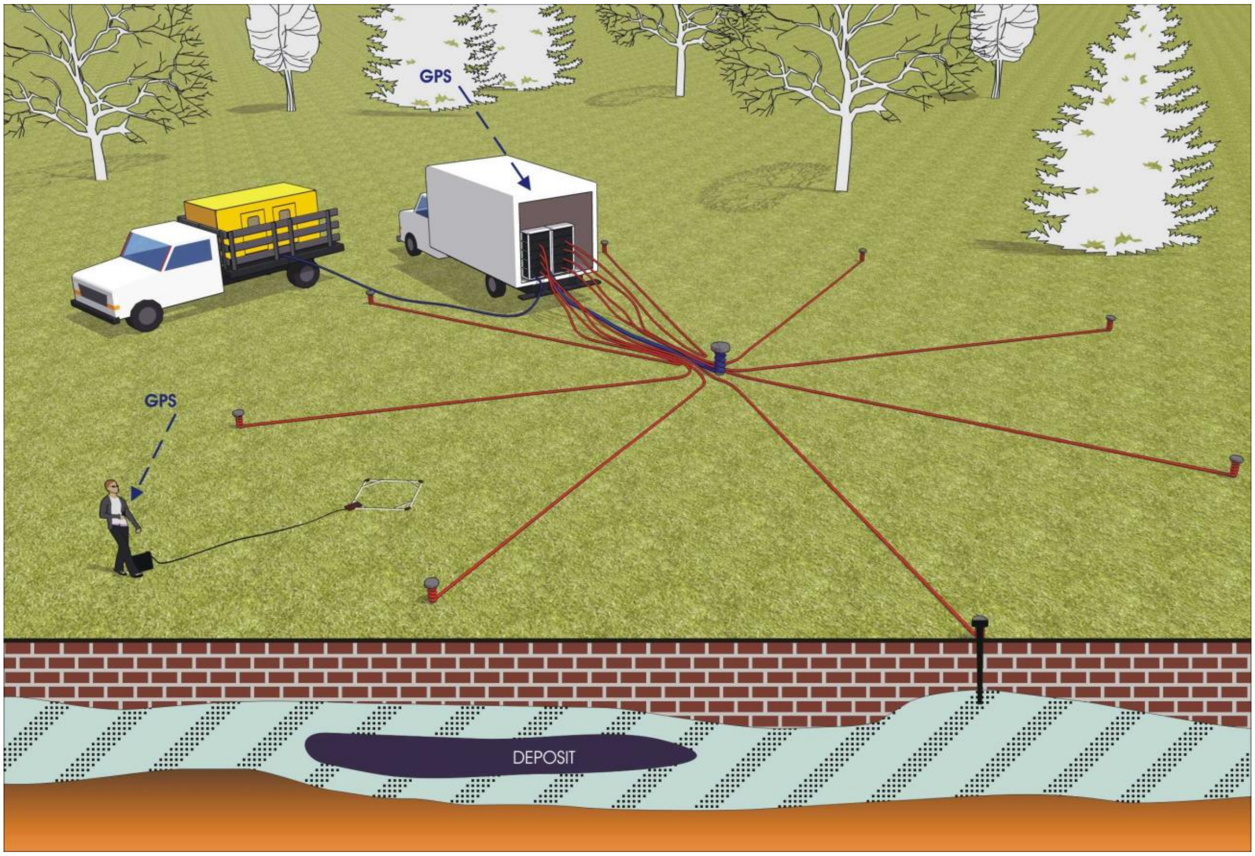

Figure 3. On land CED transmitter.

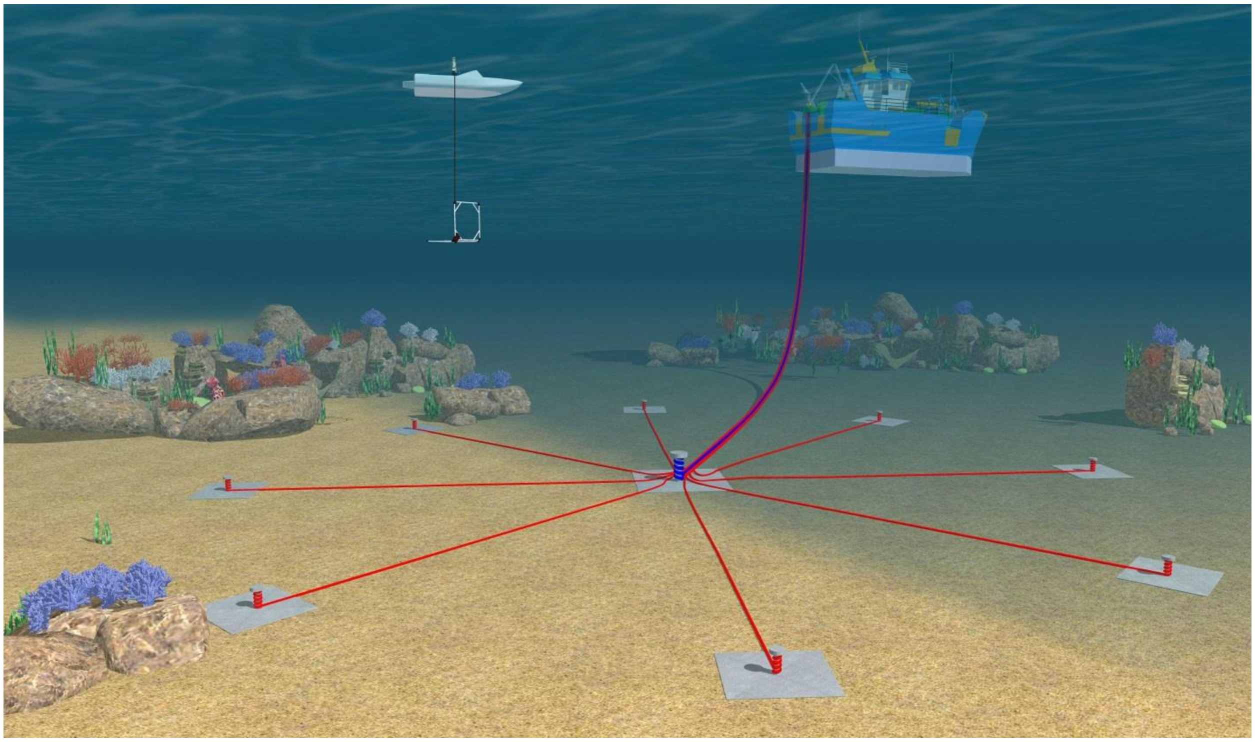

Figure 4. Offshore CED transmitter.

The main shortcoming of CED results from the necessity to provide very stable and perfectly equal currents in all legs of the transmitter dipole. This is a very challenging problem in case of large on land transmitters, in which the outer electrodes should be grounded in quite different contact resistance conditions. In addition, such cumbersome transmitters extremely hard relocate during the survey. As a result, at present, the CED system is practically realized on land as a fixed transmitter mapping tool only (Mogilatov and Balashov 1996). As such, it realizes another remarkable feature of the VED/CED systems: the complete absence of a magnetic field on the surface of 1-D earth. By distributing many magnetic field or electromotive force (emf) sensors (magnetometers or coils, respectively) within the area of interest, one can map lateral boundaries of the target using only one position of the transmitting CED.

Although, the use of the fixed transmitter mapping technology is preferable and even crucial in on land surveys compared to moving transmitter-receiver (Tx-Rx) CED arrays, the latter seem to be more geophysically efficient due to its high sensitivity to resistive targets and due to the ability to provide quantitative information regarding the resistivity distribution within the earth. Rigorous 3-D calculations also show that short offset CED transient systems provide very high vertical and lateral resolutions (Goldman et al., 2013). Despite the geophysical effectiveness, such system is not practically feasible on land, but is apparently possible in offshore surveys, where the contact resistance conditions are much more favorable than those on land and, as a result, relocating CED seem to be somewhat simpler than that on land (Figure 4). Moreover, in shallow offshore surveys, where a relatively small rigid CED can be towed by a ship from place to place, the moving Tx-Rx CED system might become a practical tool in near future. Such a system is being developed at the Institute of Geophysics and Meteorology in the University of Cologne, Germany. However, deep CED surveys both offshore and, particularly, onshore are apparently limited by a quantitative mapping of lateral boundaries of potential targets.

In the Arctic region however, the situation is significantly different. The drifting ice floes there represent an ideal platform for locating and relocating of both fixed transmitter and moving Tx-Rx CED systems (Figure 5). The CED legs are only limited by the lateral dimensions of the ice floe and could easily reach several kilometers. Thanks to very low and highly homogeneous contact resistances in all electrodes of CED, one can achieve the required high Tx moments by using existing marine EM transmitters and generators. The main disadvantage of the proposed system is the tight binding to the uncontrolled drift path of the ice floe. However, taking into account an extremely scarce high resolution geophysical information available in the high latitude Arctic regions and the lack of the appropriate geophysical methods to achieve such information, the proposed inevitable trade off seems to be well justified.

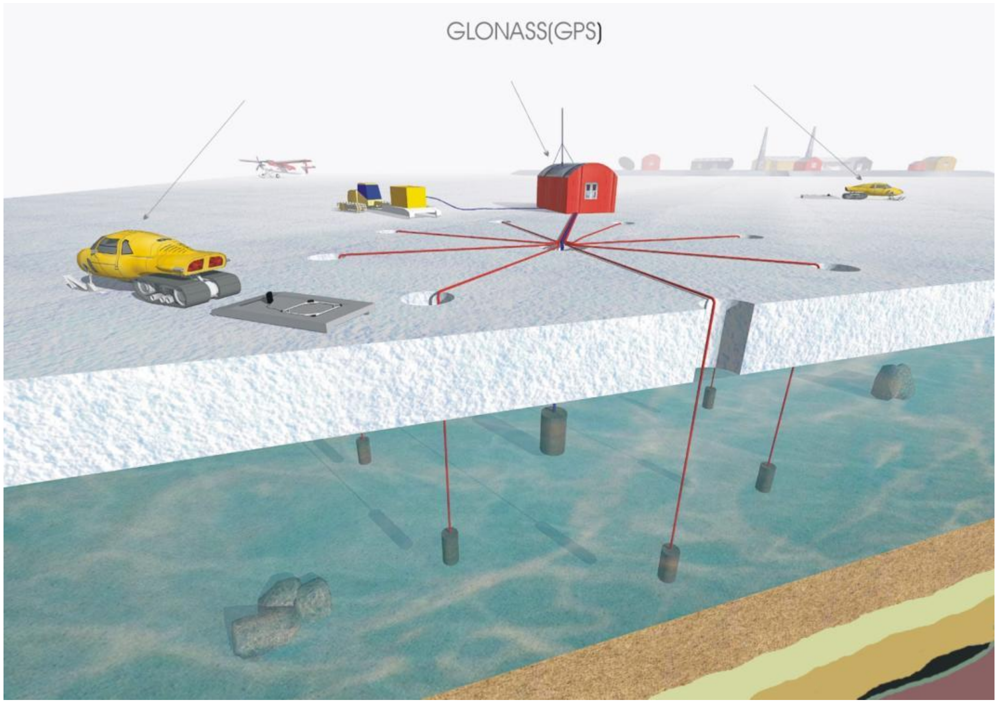

Figure 5. Layout of the CED transmitter in a drifting ice floe.

It should be noted in conclusion that the proposed high resolution mapping and sounding CED measurements, can be accompanied by more conventional DC resistivity, long offset transient electromagnetic (LOTEM) and MT measurements at practically no additional cost.