# Assessment of geoelctric field variability in Yenisei-Khatanga oil and gas province and space weather hazards for infrastructure

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## SUMMARY

The geoelectric (telluric) field variability caused by the Earth's magnetic field disturbances during space weather anomalies is analyzed for the area of Yenisei-Khatanga regional through (YKRT) - a perspective oil and gas-bearing province located in Siberian Arctic within the auroral zone. For the analysis of telluric fields and estimation of their extreme values, we use a unique experimental magnetotelluric impedance tensor database collected by Nord West *Ltd* during the regional stage of the geophysical investigations of the trough and adjacent territories. The geoelectric field spatial-frequency distributions on the Earth's surface are calculated via the impedances and harmonic approximation of external geomagnetic excitation. The correlation of obtained distributions with geological map and MT array data helps to explain the position of the areas with maximal geoelectric field distortion accounting for their geological\geoelectrical heterogeneities.

Variations in time of telluric fields at a subset of YKRT MT sounding sites are synthesized via the impedance dependences on frequency and magnetic field time series recorded during intensive geomagnetic events at the nearest stationary monitoring sites. The snap-shoots of telluric field vectors' spatial distribution are presented for the characteristic time steps of the geomagnetic variations considered, specific features of these distributions are outlined. As geoelectric responses to rapid changes of external magnetic field are the drivers of geomagnetically induced currents (the most serious threat to the grounded industrial constructions in subpolar regions) the results of the study can be used to mitigate possible damaging space weather effects on operating and projected YKRT infrastructure facilities.

**Keywords:** geoelectric fields, geomagnetically induced currents, crustal heterogeneities, Yenisei-Khatanga regional trough and oil-gas-bearing province, auroral zone

## INTRODUCTION

The theoretical and practical value of studying the Earth surface manifestations of space weather events significantly increased in the 21st century marked by the rapid economic development of high-latitude regions of Eurasia and North America. In the central sector of the Russian Arctic, of top priority are geomagnetically-induced currents' (GICs) problems in the oil and gas infrastructure.

This region offers experimental opportunities for such studies: a network of stationary magnetic observatories is being restored, large-scale arrays of magnetotelluric (MT) surveys are being collected in the frames of the hydrocarbon prospecting.

The geoelectric responses to the Earth's magnetic field rapid disturbances are drivers for most intensive GICs in earthen industrial constructions. So the analysis of geoelectric (telluric, **E**-) field variability for the territory of Yenisei-Khatanga oil and gas province, located within the highest level geomagnetic activity auroral zone (Fig. 1, 2), has clear relevance for studying possible negative space weather effects on the infrastructure facilities.

We present the results of such an analysis using the experimental data on 3D Earth conductivity and carried out this way for the first time in YKRT area.

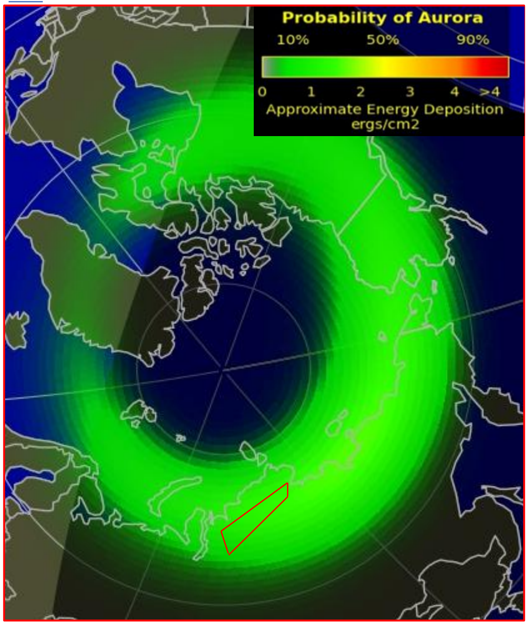


**Figure 1.** A case of NOAA Space Weather Prediction Center Aurora forecast (for 2022-07-01 19:41, UTC, NOAA Homepage). Red box marks the area of Yenisei-Khatanga regional trough (similar oil and gas province) on Taimyr peninsular.

## Data And the Analysis Approaches

The study is based on unique collection of high quality broad-band MT impedance estimates for more than 650 ($x_i$,$y_i$) sounding sites assembled for YKRT by Nord West Ltd (Fig. 2, Slinchuk et al., 2022) during the regional phase of Taimyr peninsular geophysical investigations and applies two approaches to calculate geoelectric responses: in frequency and time domains, similar to (Lukas et al., 2018; Sokolova et al., 2019) .

The geoelectric field spatial-frequency distribution on the Earth's surface is calculated via all the ensemble of experimental **Z** tensors on the basis of classical dependence of telluric (**E**) and magnetic (**B**) fields with harmonic approximation of the plane-wave external magnetic excitation (Fig. 3).

Variation in time of telluric fields at a subset of YKRT MT sites are synthesized also in planar paradigm via the impedance frequency dependences and real time series of magnetic field on the base of stable forward and inverse Fourier transform routines. For calculations GIS INTEGRO (Cheremisina et al., 2022) are also used. Specially selected magnetic data were recorded during intensive space weather events at the nearest stations of the Russian Arctic geomagnetic monitoring network (Kozyreva et al., 2022) (Fig. 2).

The variation of the voltage in pipelines are estimated as simple line integral of vector **E**($x_i$,$y_i$,$t_j$) estimates over pipe geometry for a set of fixed time steps $t_j$.

## Discussion of the Results

The variability of the geoeletric fields on the area of Yenisei-Khatanga trough are represented in the study results by spatial distributions of the amplitudes of horizontal electric field **E**($x_i$,$y_i$,T), induced by the homogeneous harmonic 1 nT geomagnetic field $\mathbf{B_h}$(T) oriented geographically N-S and E-W for number of characteristic periods (Fig. 3). The temporal variability is described through **E**($x_i$,$y_i$,t) variations with time, synthesized on magnetic storm or sub-storm records in NOK and DIK for some YKRT sites($x_i$,$y_i$) representin different geoeletric structures. Also snap-shoots of telluric field E($x_i$,$y_i$,t) vector spatial distribution are presented for the characteristic time steps $t_j$ of the geomagnetic variations considered.

YKRT stretches for over 1,000 km and has nearly 20 km-thick MZ sedimentary cover (electrical resistivity of 5-20 Ohm·m) with several basement uplifts geophysically established within the trough bed. It is surrounded by East Siberian Platform in the South and the Taimyr orogen in the North, which are composed of Paleozoic and older consolidated sedimentary\metamorphic complexes (100-400 Ohm·m) partially, penetrated by even more resistive intrusive bodies and broken by faults (Fig. 2). Spatial distributions over the YKRT area of effective apparent resistivity estimated on regional impedance collection reflect these geoelectrical contrasts at corresponding skin depths. The correlation of obtained **E**-field variability maps (amplitude for specific frequencies) and vector snap-shoots (for specific time steps of magnetic storms) with geological and resistivity data helps to explain the significant features of geoelectric distortions' field as products of 3D geological\geoelectrical heterogeneities.

Both maps of spatial geoelectric responses and time series of synthetic **E**-fields provide the ideas of possible extreme values/directions of geoelectric variations on the studied area, which are correspondent with but give much more details then similar small scale maps constructed recently in (Kozyreva et al. 2022) for central segment of Russian Arctic on the base of global 3D conductivity model (Alekseev et al., 2015).

The geo-induced voltage across operating and projecting pipelines in the region, calculated on synthetic geoelectric field time series, can exceed the regular levels of pipeline cathodic protection.

## Conslusion

Our study describes the spatial and temporal variability of geoelectric field on the territory of perspective Yenisei-Khatanga oil and gas province. This component of the Earth's electromagnetic sphere is the main prerequisite for calculations of GICs in grounded technological systems, particularly – in pipelines. The following inferences seems to be useful for mitigation of possible destructive impacts of space weather on operating and future YKRP infrastructure facilities.

- For an adequate assessment of these risks it is necessary to carefully analyze the geoelectric structure of the area where a facility to be constructed. Heterogeneities in the distribution of electrical conductivity of the Earth's crust are the major factor for the GIC patterns, by damping or, in opposite, significantly amplifying amplitudes of the currents and modulating the spectral composition. The most sever GICs are foreseen in the frames of YKRT, where perspective for hydrocarbons, resistive and highly heterogeneous in geoelecrtic properties Paleozoic formations are spread. The maps describing variability of regional geoelectric fields can serve as space weather hazard maps for subpolar oil and gas provinces.
- The estimates of vectors of the horizontal geoelectric field **E**(x,y,T), induced by the harmonic oscillations $\mathbf{B_h}$(T), vary greatly in magnitude and direction. At frequencies that carry most of the disturbed field's energy, they have the maximum amplitudes in the range from <1 to ~50-100 mV/km at a unit amplitude of external magnetic field variations. Thus, even with moderate amplitudes of geomagnetic variations during substorms (300-500 nT), their geoelectric responses in the area of Pz formations can reach 15 V/km and more. As synthesized E-field time series reveal, during considered real mild magnetic storm (Dst ~-60 nT) telluric field variations for several geoelectrical structures of the YKRT might have exceeded 5-7 V/km.
- Voltage variations estimated using as input data synthetic time series of the geoelectric field in sites along projected or operating (Messoyaha-Norilsk) pipelines might be rearded as threshold values' objective porxi for cathodic protection scheme design/optimization for mitigation of severe spase wether impacts.

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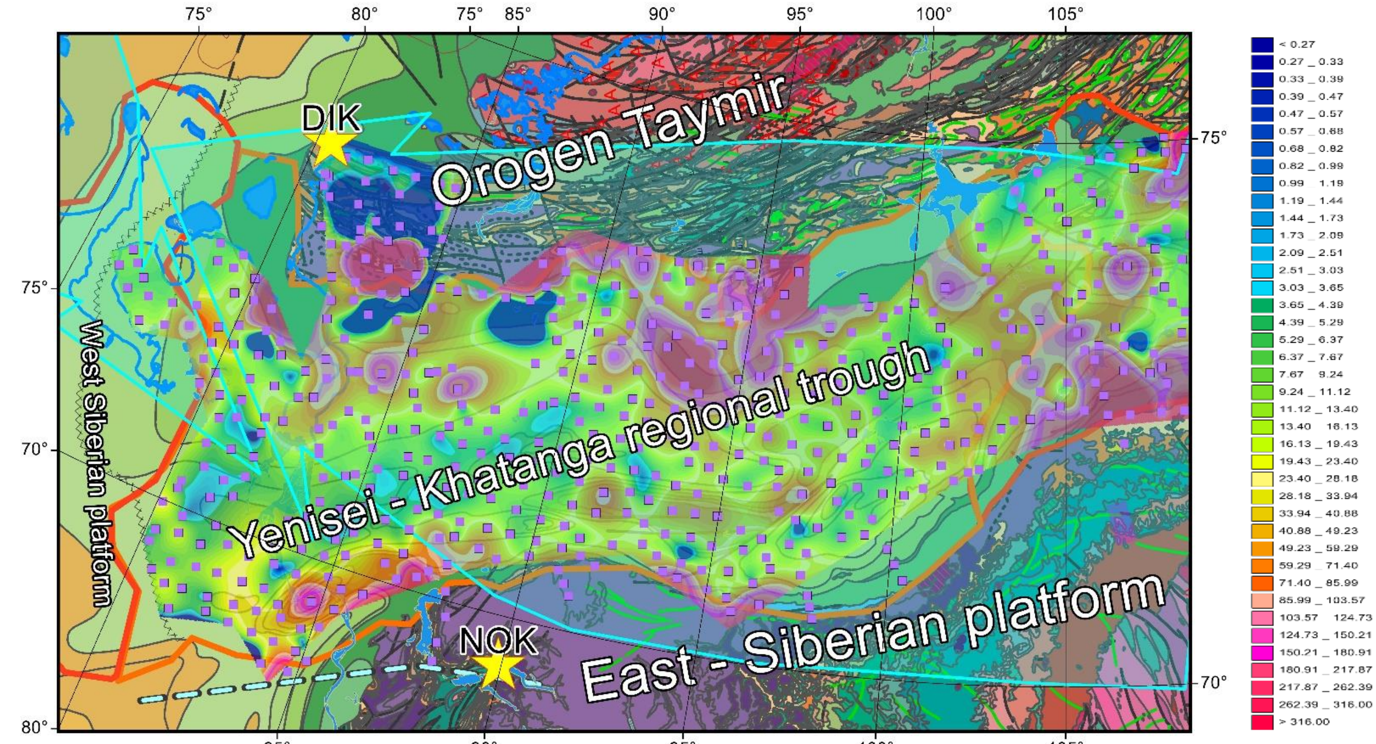


**Figure 2.** Yenisei-Khatanga oil and gas province MT sounding sites (Slinchuk et al., 2022) (purple squares inside orange contour line) and the nearest magnetic stations (DIK- Dikson, NOK- Norilsk, yellow stars) on the background of the regional geological map on Northern margins of East Siberian platform and distribution of corresponding effective apparent resistivity estimates (for T=100c), according to the color palette (in Om·m). Blue dotted line – operating Messoyakha-Norilsk gas pipe. Transparent blue arrows show a schematic position of western and eastern electrojets at local midnight on the meridian 100°E.

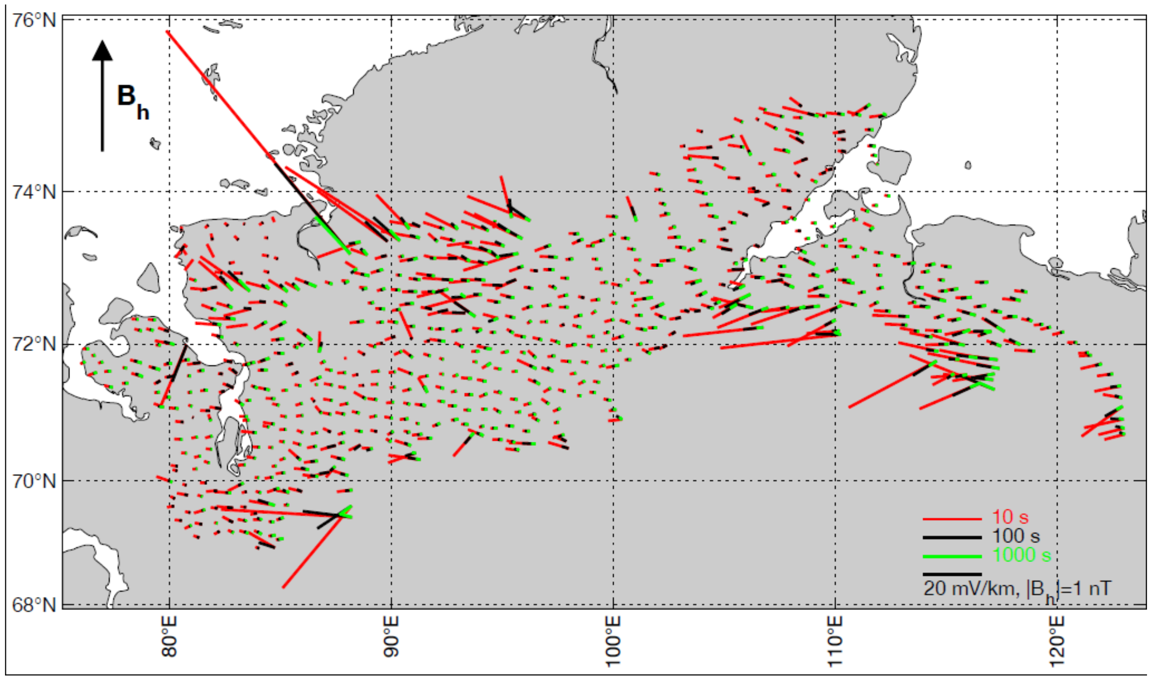


**Figure 3.** Spatial distribution on the Yenisei-Khatanga trough of the experimental impedance data-based vectors of the horizontal geoelectric field **E**(x,y,T), induced by the homogeneous harmonic geomagnetic field $\mathbf{B}_h$(T) with an amplitude of 1 nT and oriented geographically N-S, for the periods T=10 s (red), 100 s (black), and 1000 s (green). The scale bars show 20mV/km length of geoelectric field vectors.