PROTECTING THE POWER GRID

UTILIZING THE MAGNETOTELLURIC ARRAY 2022 (MTA22)

Project Description

Geomagnetically induced currents (GIC) can affect the normal operation of regional electrical infrastructure including power distribution, communication and pipeline systems. GIC are a manifestation at of space weather at ground level. The sun is the main source of space weather. Sudden bursts of plasma and magnetic field structures from the sun, called coronal mass ejections (CME), along with bursts of radiation, or solar flares, all cause space weather effects on Earth. The Aurora Borealis is a magnificent manifestation of CME and flares. These events increase corrosion of steel pipelines and can damage high-voltage power transformers, which are of important economic and practical concerns. Space weather can produce electromagnetic fields that induce extreme GIC in wires, disrupting power lines, and even causing wide-spread blackouts.

GIC were first observed on the emerging electric telegraph network in 1847–8 during a Solar storm. As electrical technological development that has expanded, electrical networks have made the significance of GIC greater in modern society. The strongest geomagnetic storm on record is the Carrington Event of August-September 1859, named after British astronomer Richard Carrington. During this event, GIC electrified telegraph lines, shocking technicians and, in some location, setting telegraph office paperwork on fire. During this storm, Aurora were visible as far south as Cuba and Hawaii. Another significant event took place on March 13, 1989 when a powerful geomagnetic storm triggered a major power blackout in Canada that left six million people without electricity for nine hours. The CME disrupted electric power transmission from the Hydro Québec generating station and even melted power transformers in New Jersey.

Electrical currents in the magnetosphere generate a large-scale, time-varying magnetic field that in turn induces telluric, or Earth, currents to flow in the electrically-conductive Earth in accordance with Faraday's Law of electromagnetic Induction. This Law describes how an electric field is generated by a time-varying magnetic field. At the surface of the Earth, the electric field induced by a Solar disturbance causes the GIC to flow with greatest intensity in structures having the greatest electrically-conducting structures; powerlines, pipelines and communications This illustrated in Figure 1.

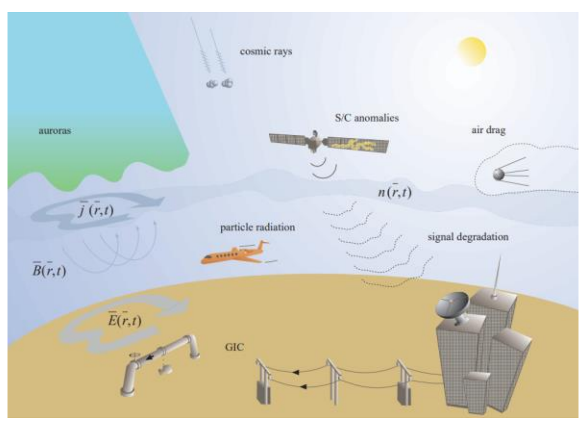

Figure 1. Highlights of the effects of space weather. E is the electric field, B the magnetic field, and j the electric current density (Pulkkinen, 2003)

Often described as quasi direct current (DC), GIC are a relatively low-frequency phenomena. For GIC to be a hazard to infrastructure and technology, the current has to be of a magnitude and occurrence that makes the equipment susceptible to either immediate or cumulative damage. The size of the GIC in any network is governed by the electrical properties and the topology of the network, in addition to the electrical conductivity of the Earth. Significant variation can occur over periods ranging from a few seconds to about an hour or so, meaning that induction occurs in the Earth's upper mantle and crust. The largest magnetic field variations are observed at high latitudes where GIC have been regularly measured in Canadian, Finnish and Scandinavian power grids, and pipelines since the 1970s. GIC measurements of tens to hundreds of amperes have been recorded. GIC have also been recorded at mid-latitudes during major solar storms. Potential risk of GIC in low latitude areas may exist in conditions where a storm commences suddenly due to high, short period rate of field change that occurs on the day side of the Earth. GIC has influence at all latitudes, hence this phenomenon has been judged to be an important study on a nation-wide basis. One important study objective is to identify those regions where GIC will be most intense. Those regions will be ones that are underlain to great depth with rock that is electrically resistive. And the most efficient method of obtaining information about the deep electrical resistivity structure of the Earth is the Magnetotelluric (MT) method.

The MT method is a passive geophysical technique that measures the time varying natural electric and magnetic fields at the Earth's surface. These measurement data are used to image the electrical resistivity of the subsurface that can be related to rocks and fluids within the Earth to depths as great as tens of miles. For the past several years, Oregon State University (OSU) has been conducting an MT survey of the Continental US. Professor Adam Schultz, OSU, is the principal investigator for the National Science Foundation-funded EarthScope MT study, an ambitious, multifaceted program to investigate the structure, dynamics, and history of the North American continent (www.earthscope.org/).

Since 2010 Green Geophysics (GG), under subaward from OSU, have acquired data at several hundreds of sites for the MT Array. To date, MT data have been acquired on a 70 km grid throughout much of the country as shown in Figure 2. Footprints in the Northwest USA and the North Midwest have been process and interpreted by several groups (Patro and Egbert, 2008; Zhdanov et al., 2011; Kelbert et al., 2012; Zhdanov et al., 2012; Bedrosian and Feucht, 2013; and Meqbela et al., 2013) providing unprecedented three-dimensional views of electrical conductivity variations, in the crust and upper mantle, shedding new light on the physical state, tectonic history, and geodynamic processes of the region including the deep structure of the Yellowstone area and the Cascadia chain of volcanos along the western US from Mt. Rainier in WA to Mt. Shasta in CA. The data acquired in the Midwest was used for a spectacular image mid-continental rift (Bedrosian, 2016). Studies are underway in other portions of the dataset. All data are publicly available at http://ds.iris.edu/mda/EM/ and http://ds.iris.edu/spud/emtf. Recently, resistivity models generated from these data are being used to produce GIC-hazard maps (Love et al., 2018a; Love et al., 2018b).

In 2021, we plan to complete acquisition of sites in AZ, CO, KS, NM & UT and start OK and TX as shown in Figure 3. Field conditions will vary widely from forests, deserts, agricultural areas to highly urban environments, but we anticipate that data will generally be of high quality. TX, OK and the south will be completed in the following years. The continental scale dataset is planned to be complete in 2022.

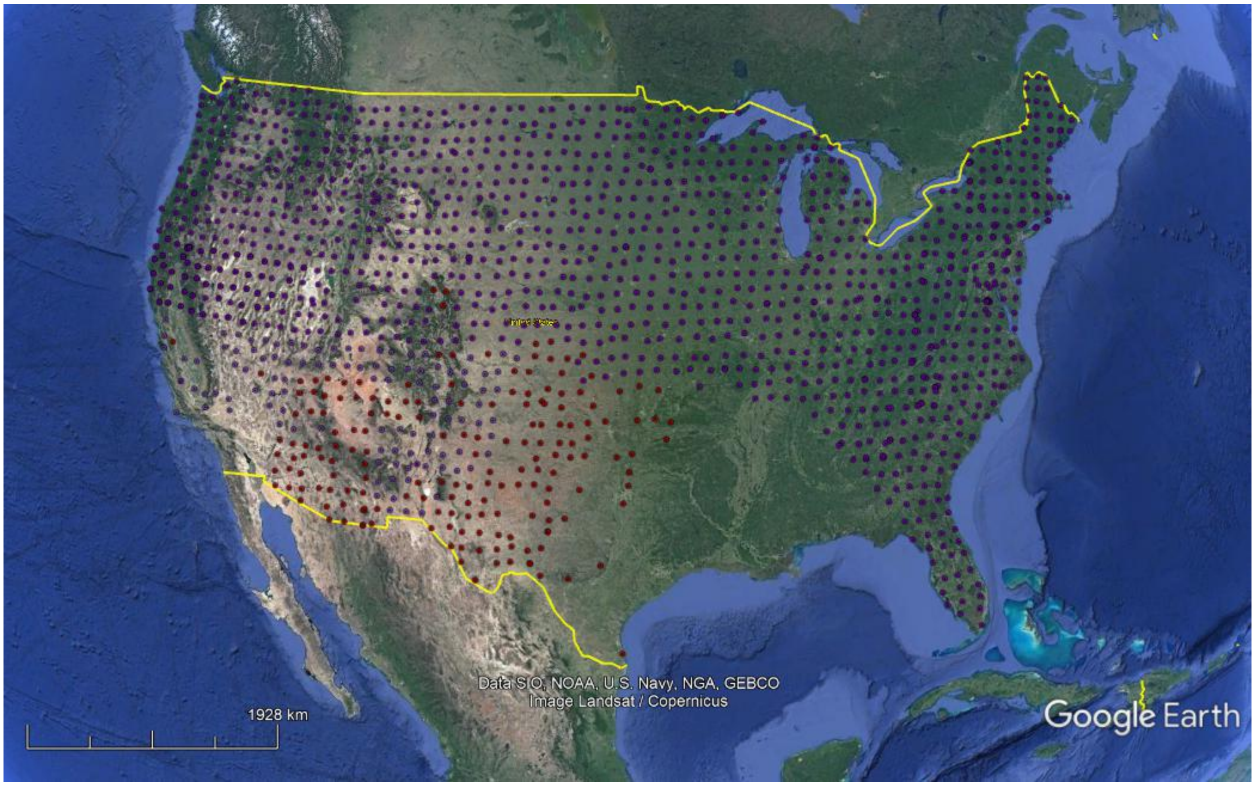

Figure 2. Map of MT Array completed to date under 2006-2018 NSF EarthScope funding, 2019-20 NASA GIC funding, and the first two years of funding through the US Geological Survey.

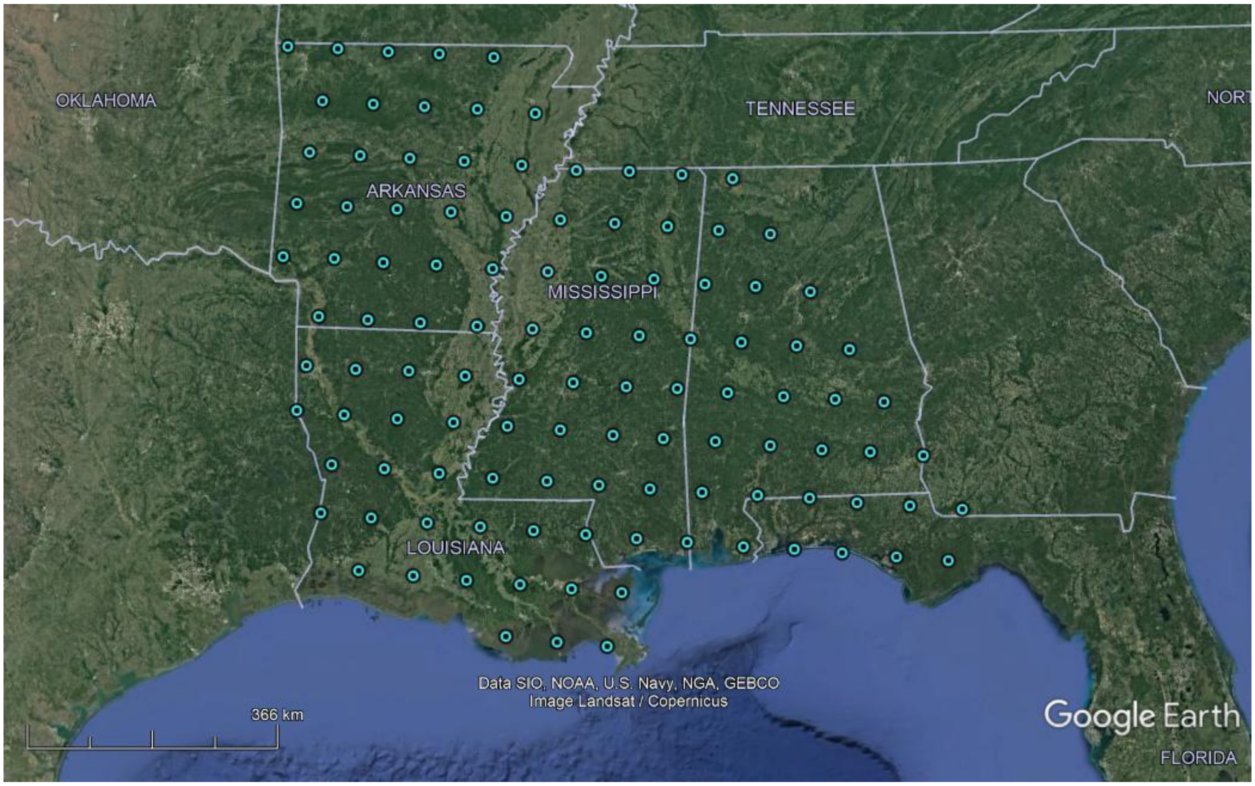

Figure 3. Proposed 2022 station locations denoted in aqua dots.

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Instrumentation

Installation

Traditionally the magnetometer unit (vertical tube) is buried in the ground in a large plastic bag as shown in Figure 7. The hole is ~3’ in depth. The receiver is also bagged and buried in a shallow hole, mostly for security. The connector cable is also covered with soil so that the main equipment is not visible and only disturbed soil can be seen.

Figure 7. MT magnetometer installation – bury in bag, align, level, and bag connector.

The electrodes used to measure the electric field are installed in a buried hole at least 1' deep in a mud slurry. Figure 8 shows an electrode placed in hole partially filled with a mud slurry. The electrodes are completely buried, but the wire (usually about 12 gauge or larger) connecting the electrodes to the receiver are laid on the surface. At the site center the receiver is connected to a deep-cycle 12V car/truck battery. The negative pole of the battery is grounded to the Earth through a 12 gauge or larger diameter insulated electrical cable connected to a grounding rod placed at least 30' distant from the magnetometer sensor. The grounding wire is solely an instrument ground.

The instrument and battery are placed in a water-tight instrument case or wrapped in a plastic bag and a space blanket, and then buried so that the entire installation is below ground surface. A thermal blanket, shiny side facing up serves two purposes: 1) keeps the system thermally insulated and thus reducing thermal effects on the electronics, 2) provides an easy way to dig up the system – simply dig and the pull up the corners of the thermal blanket.

Figure 8. View of electrode placed in hole before burying.

If there is potential for damage to the electric field lines from animals (usually cattle in the west), vehicles, etc., or at the landowner requests the electric field wires are trenched by hand digging or laying the wire through plastic conduit on the surface. The magnetic cable will always be buried. With the equipment buried the site will have almost no equipment visible on the surface. The GPS receiver, which looks similar to a computer mouse, must sit on the surface to have access to the sky.

Deployment

For the purposes of clarification, the following definitions apply:

- **Install** — construct site and install a MT system to form an operating station and initiate the recording run.
- **Service** — stop acquisition, download recorded data, install fresh batteries, and restart data acquisition.
- **Extract**—stopping acquisition, uploading the recorded data, removing and packaging the instruments and equipment, and restoring the site to conditions generally to original contours.

Given the distances involved and the required measurement times, the total field effort per station will be approximately 2 days: 1 day of installation, ½ day for servicing, and ½ day for recovery of the instruments. The crew will service the system within the approximately 3-week occupation time. A vandalized/damaged station would obviously need to be redeployed until a minimum of 21 days had been recorded and data quality achieved.

Before field operations begin an orientation and training session for field personnel and other interested parties consisting of safety procedures, field operations, forms and maps are conducted. The property owner will be kept appraised of comings and goings of the crew, and interested parties are always welcome to observe installation or extraction.

Permission

Permission is requested such that data acquisition and crew access is available only within a limited time frame. If sites are located behind fences or locked gates, access must be obtained for the crew, and these will be kept closed/locked at all times – this can be an issue on both private and public lands.

The environmental impact is minimal. There are essentially no hazardous materials used in the installation or nor risk of shock except by mishandling of the batteries by the crew. The environmental impacts are limited to the shallow burial of the data acquisition system and batteries and possible cable trenches. All equipment is buried, except for wires, as discussed below, and the completed installation site will have almost no equipment visible on the surface except for a sign if needed and wire. The N-S and E-W wires can be buried, if necessary, such as in a cow pasture, but are usually left on the surface. Field crew presence is minimal as well; it usually takes less than half day to dig the holes, install equipment, lay out cable, backfill the holes and depart the site.

Siting and Occupancy Criteria

General siting requirements for each of the MT sites include:

- Sites will be spaced on a regular grid with spacing between sites of ~70 km.
- An error circle of ~15 km around each nominal grid element to locate a site is allowed.
- Site must be available for up to 21 days of continuous equipment occupation, with the ability for the crew to visit the site during the intervening period to check data or service or re-install the same or a different unit at the same site or relocate to new site in the event that approximately 21 days of data or acceptable quality were not recovered from a site.
- To mitigate cultural and ambient electromagnetic noise, the equipment is best located in areas that satisfy the following siting criteria:
    - Flat (although not necessarily level), square ~100 m on a side;
    - Not be adjacent to large or isolated trees;
    - At least 10 m (30’) from un-electrified fences with wooden posts;
    - At least 100 m (300’) from houses;
    - At least 100 m (300’) from un-electrified fences with metal posts;
    - At least 100 m (300’) from buried pipes with no cathodic protection;
    - At least 100 m (300’) from local power lines and 500-1000 m from transmission lines;
    - At least 500 m (1500’) from primary roads and 100 m from secondary roads;
    - At least 500 m (1500’) from working pumps;
    - At least 500 m (1500’) from electrified fences;
    - At least 2 km (1.2 miles) from schools, playgrounds, etc.;
    - At least 3 km (1.8 miles) from interstate highways and railways;
    - 5 km (3 miles) or more from buried pipes with cathodic protection;

- At least 5 km (3 miles) from electrically-powered circular irrigation systems;
- At least 10 km (6 miles) from DC interstate power lines.

Key Personnel

Oregon State University (http://ngf.oregonstate.edu) is the lead organization. The principal investigator is Professor Adam Schultz, College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, Oregon, 541-737-9832, adam@coas.oregonstate.edu**.**

Green Geophysics, Inc. (www.greengeophysics.com) is a geophysical services company based in Berkeley, CA. GG, specialists in electromagnetic exploration and academic support, is under contract with OSU to site and permit stations, acquire data and assure data quality. Louise Pellerin, Ph.D., is the owner and president of Green Geophysics. 510-326-7269, pellerin@greengeophysics.com. Jeff Johnston is vice-president, jeff@greengeophysics.com, 510-334-6137

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Any of which may be working in any given State, with an assistant, will be doing the installation, service, and extraction. Crew members will be rotating on and off throughout the field season.

Please visit https://greengeophysics.com/mt-array to read more about the technical aspects of the project, including instrumentation, and view the photo gallery of the crew working around the country.

To learn more about Space Weather and GIC check out
https://www.youtube.com/watch?v=34t7A__pWQA&t=3s