IRIS MT Facility at OSU

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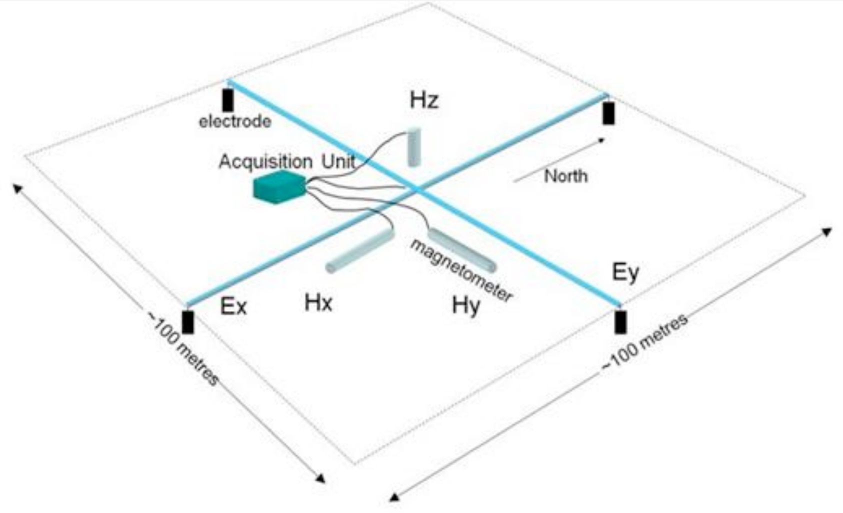
The magnetotelluric method sensor configuration

By measuring the electric and magnetic fields at the Earth's surface due to induced electric currents in the subsurface, we determine the electrical resistivity structure of the **<u>near surface</u>** through the **<u>upper mantle, and into the Transition Zone.</u>** **The image at left is of an ultra-long-period installation in northern Minnesota designed to be thermally stable**

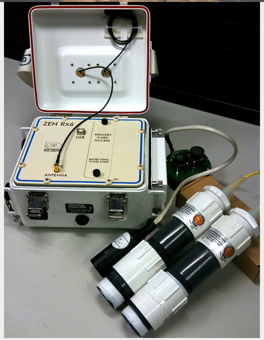


The magnetotelluric method deployment modes

A variety of MT instruments (long-period and wideband) deployed in transportable array configuration (bottom left), quick production style mode using novel E-field sensors (top right), and continuous observation mode for 4-D MT work (bottom center)

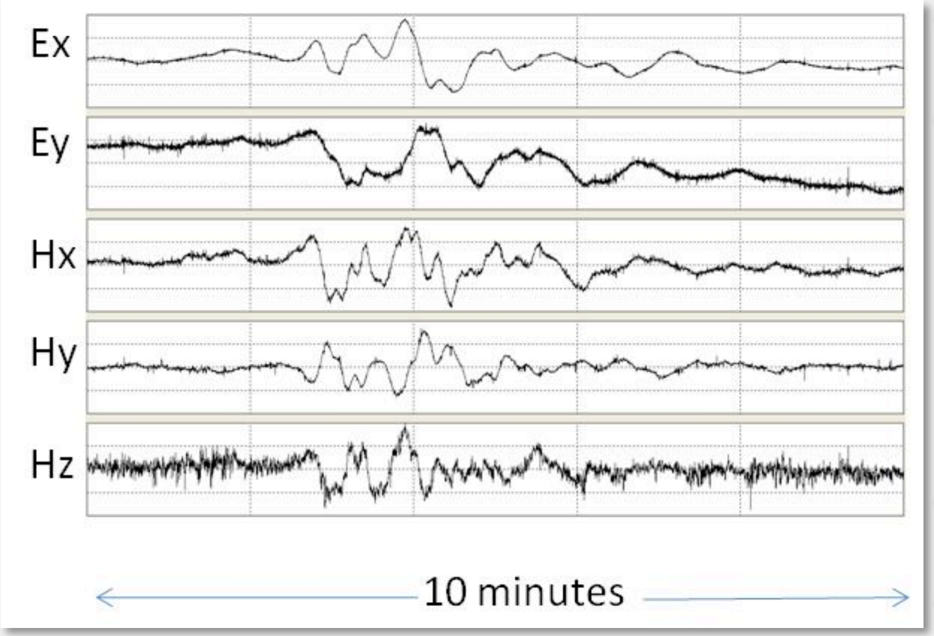
MT FA LP 10 Hz ≤ ≤ 10 Hz

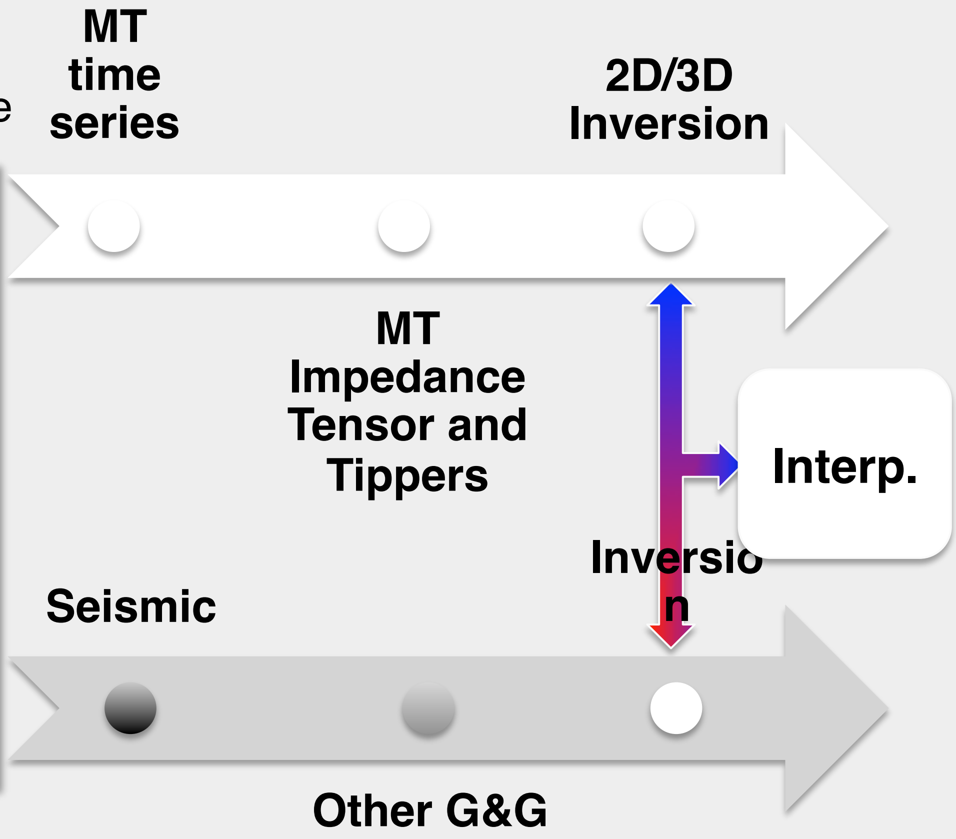
MT FA WB 10^{-5} Hz ≤ *f* ≤ 10^{6} Hz



MT – the OTHER 5 seismic channels!

The physics of MT differs from seismic
(diffusion rather than wave)
but shared goal – to image the crust and mantle





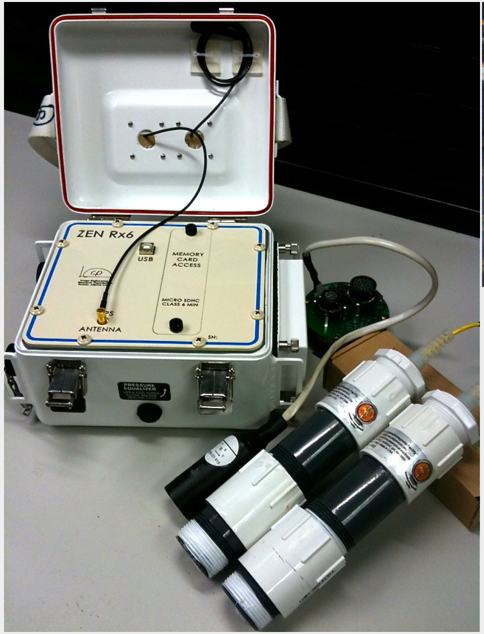
The magnetotelluric (MT) method for imaging Earth conductivity structure – what we measure, and what we measure it with

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yz} & Z_{yy} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \end{bmatrix} + \mathbf{U}$$

$$H_z = \begin{bmatrix} T_{x,z} \\ T_{y,z} \end{bmatrix} \begin{bmatrix} H_x & H_y \end{bmatrix} + \mathbf{U}$$

Simultaneous measurements of the electric and magnetic fields allow for the calculation of the impedance tensor **Z(*f*)** and tipper **T(*f*),** which are complex and frequency-dependent. **Z** and **T** are inverted to yield models of the electrical conductivity structure of the Earth. Lower frequencies map to greater depths.

OSU/Zonge ultra wideband MT system – high resolution

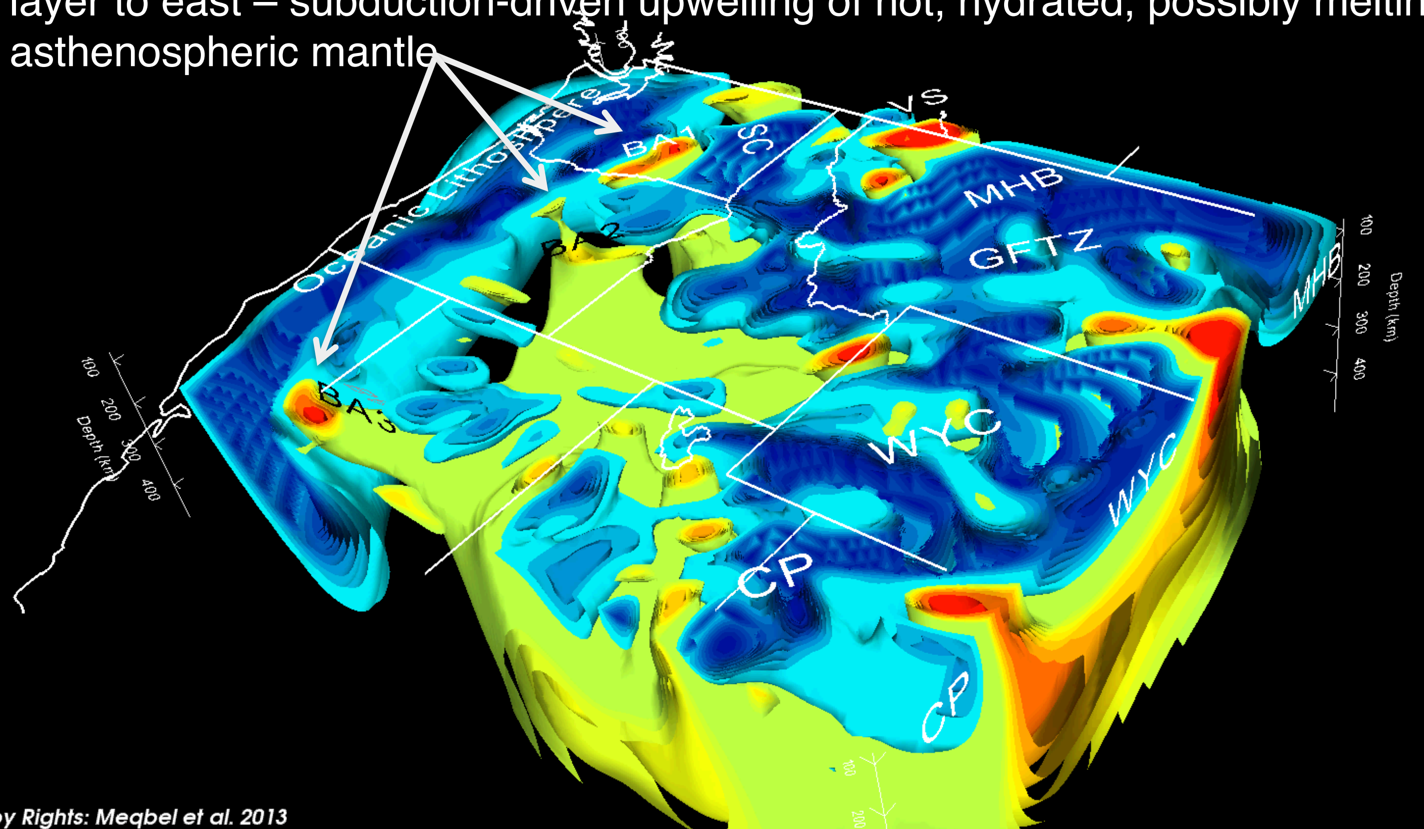


Typically we use 50-100 m long electric field dipole receivers, triaxial fluxgates or induction coils

OSU/EarthScope long period MT system – deep imaging

MT TA NW Quadrant CONUS

BA1,2,3 Backarc conductors in "plumes" connect to deep asthenospheric layer to east – subduction-driven upwelling of hot, hydrated, possibly melting asthenospheric mantle



USArray MT TA, MT BB, MT FA

MT TA

631US stations completed 2006-2014

95 Canadian stations completed 2006-2012

71US stations planned for 2015

MT BB

7 stations operating ≦2008 – 2013

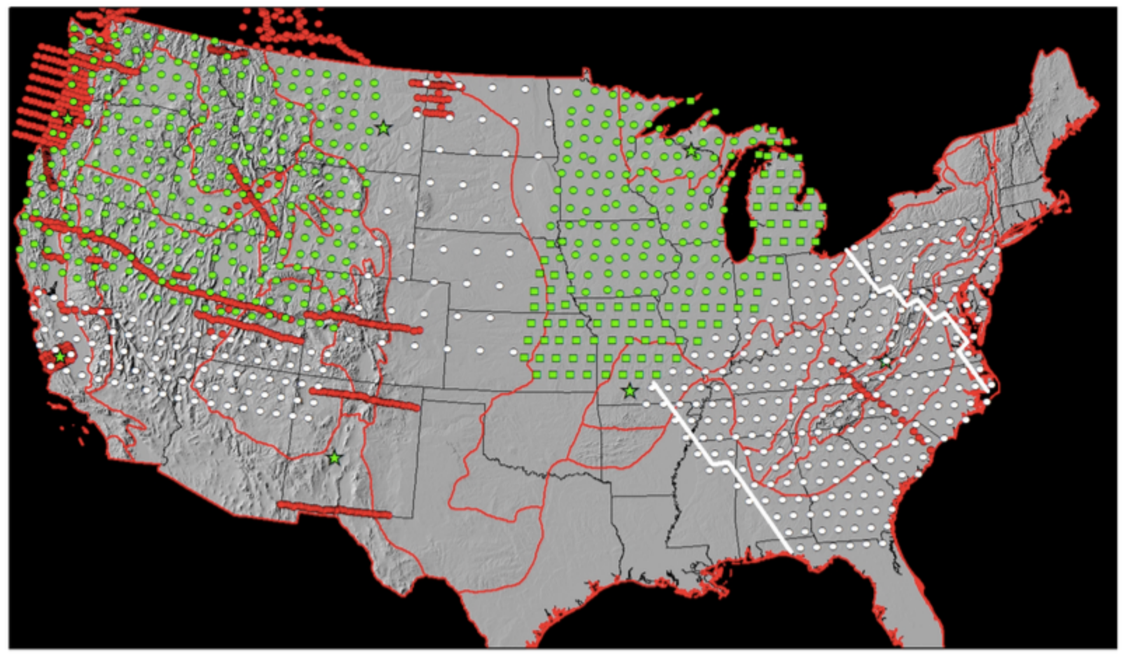
MT FA

75 long-period land MT stations and 75 marine MT stations for MOCHA

150 wideband stations for iMUSH

132 long-period stations for RGR

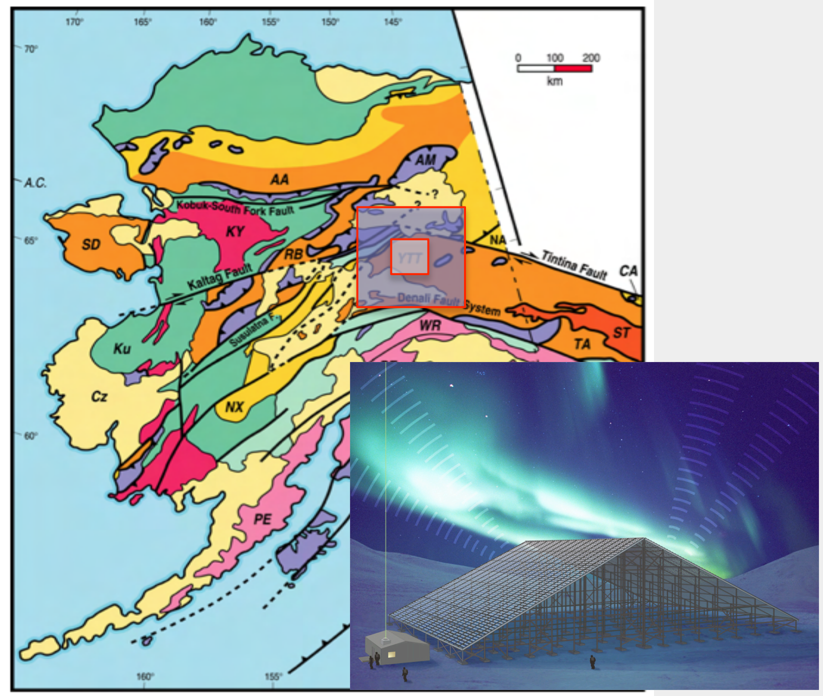
25 synchronous long-period MT for Alaska/INSPIRE



MT FA Alaska

FA: Joint AGS/ES ionospheric/GIC/MT imaging addressing a $2T risk; aid completion of full MT TA in CONUS

FA: Yellowstone Caldera wideband MT; 2016 fieldwork start



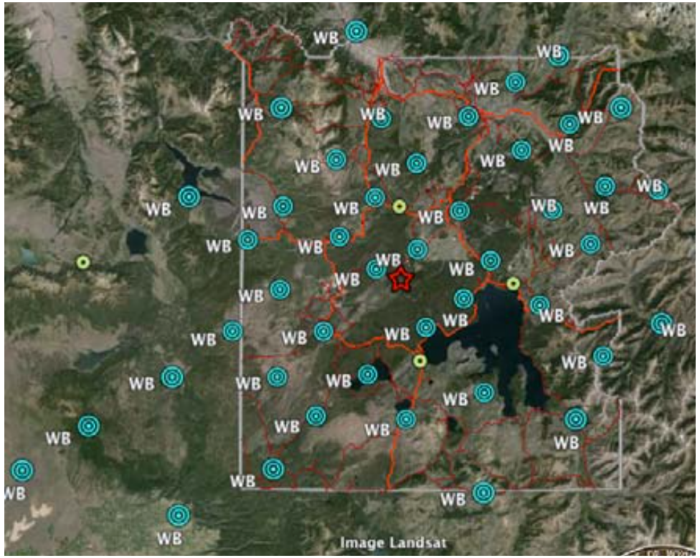


Figure 8. Proposed MT survey at YS: blue=WB MT proposed. Green=MT TA sites. Grey line =YSNP boundaries. Red lines=YS trails/roads. Red star is (0,0) of synthetic test grid of Figure 9.

STAFFING

- PI and Facility Director: Adam Schultz
- MT lab manager, instrumentation technical support: Brady Fry
- 2nd MT instrumentation technical support, MT FlexArray support and MT TA crew chief: Kyle McDonald
- MT Data QC oversight, problem solving: Gary Egbert
- MT Data QC operations: Anna Kelbert/Svetlana Erofeeva
- Additional Technical and Field Support as Required: Esteban Bowles-Martinez, Naoto Imamura, L Roy Bonner, hourly field crew

DATA FLOW

Data management operations

- Target is to have each data acquisition campaign (typically MT TA annual array) fully QC'd, with time series in dataless SEED, MT transfer functions in EDI and SPUD XML formats, uploaded to IRIS DMC within 3 months of conclusion of field operations
- Overall responsibility for this is Gary Egbert's, with Anna Kelbert being the primary operational QC staff member

THE NATIONAL GEOELECTROMAGNETIC FACILITY

1) IRIS/EARTHSCOPE POOL 2)DOE POOL 3) NGF POOL

Current inventory (94 land MT instruments, 1 Marine combined MT/CSEM/seismic instrument):

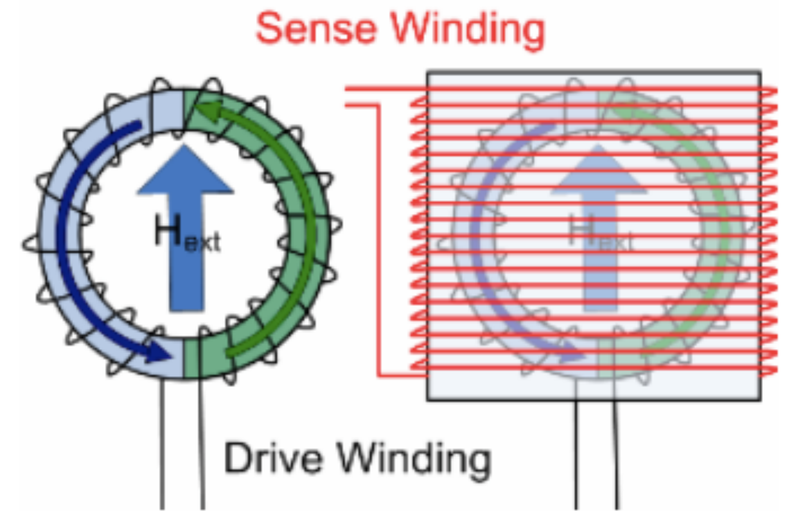
68 NIMS long-period MT systems

- 28 ES owned transportable NIMS instruments (including 7 previous MT Backbone instruments converted into transportable instruments in 2015);
- 1 ES owned LEMI-417 transportable instrument;
- 25 NIMS on indefinite loan from UW (former EMSOC instruments). Title is being transferred to OSU.
- 17 NIMS receivers (various states of repair), 14 NIMS magnetometers (9 good) on long-term loan from the University of Manitoba

SENSORS: THE MAGNETIC FIELD

The fluxgate magnetometer

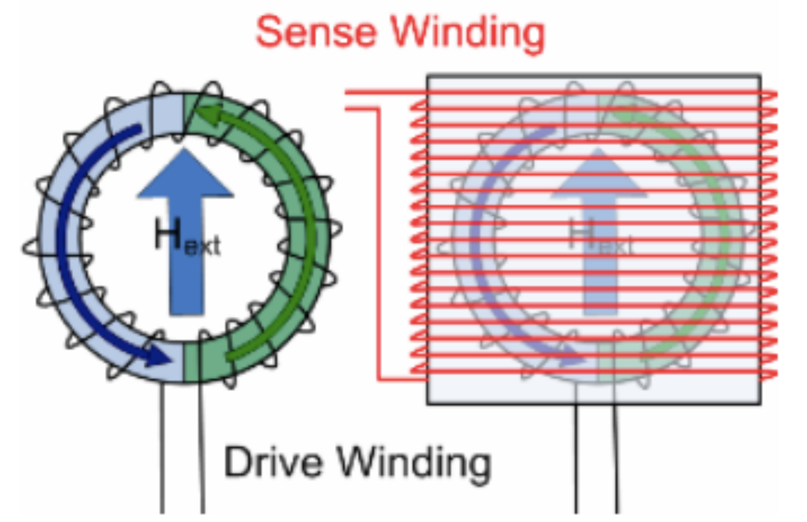
- Invented by Victor Vacquier in 1930's. Used extensively in WWII for antisubmarine warfare, then instrumental in verification of plate tectonics by detection of magnetic striping of seafloor
- There are several variants of the fluxgate:
  - Rod Core
  - Racetrack Core
  - Ring Core
- Most of our long-period MT instruments employ the ring-core approach, which I'll describe in the following slides



SENSORS: THE MAGNETIC FIELD

The fluxgate magnetometer

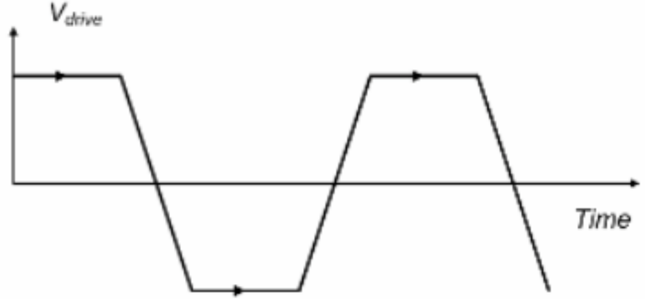
- Fluxgate sensors employ cores of a highly magnetically permeable alloy around which are wrapped two coil windings: the drive winding and the sense winding (as shown in the figure).
- This core is set up to measure the field in the direction of Hext. As the current flows through the drive winding, one half core (green) will generate a field with a component in the same direction as Hext and the other (blue) will generate a field with a component in the opposite direction to Hext.

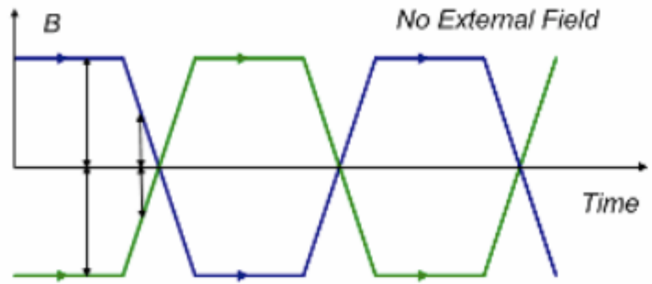


SOURCE: IMPERIAL COLLEGE LONDON

SENSORS: THE MAGNETIC FIELD

- An alternating current runs through the drive coil wrapped around the ring core. An example of a drive current waveform is seen in the figure at the top right.
- This waveform induces a magnetic field through the drive coil, which drives the highly permeable core material to magnetic saturation
- In the absence of an external field Hext, the blue half of the ring core will saturate when the magnetic field induced by the drive coil reaches a certain value, and the green half of the ring core will saturate at exactly the same time, but with opposite polarity
- The magnetic fields due to the blue and green parts of the ring core will always cancel each other out





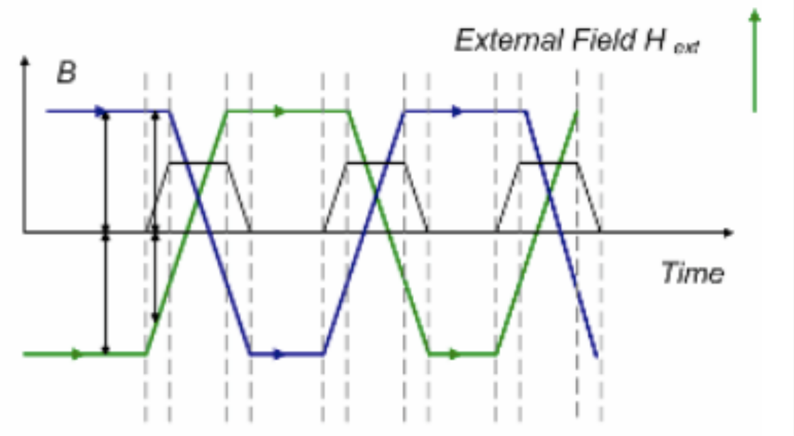
SENSORS: THE MAGNETIC FIELD

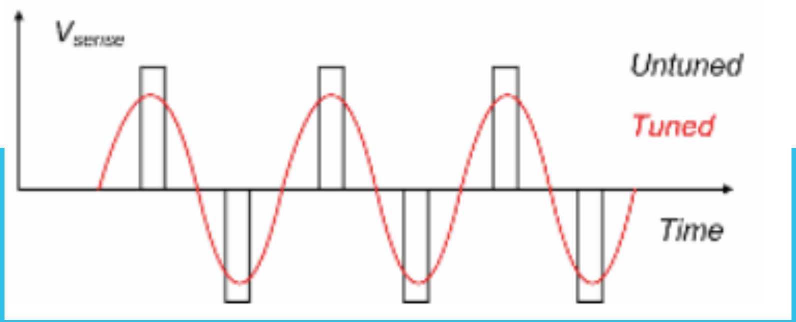
- When there is an external field, the half core generating a field in the opposite direction of the external field comes out of saturation sooner and the half core in same sense as the external field comes out of saturation later

- During this time the fields do not cancel out and there is a net change in flux in the sense winding

- The net change in flux induces a voltage

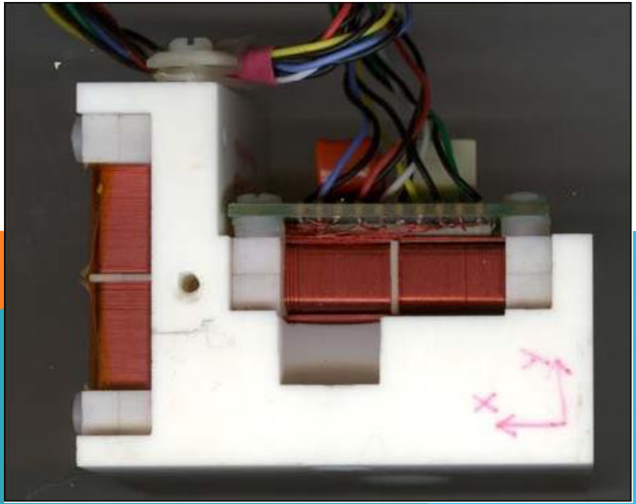
- Toward the end of the transition, the half core now generating a field in the same direction as Hext goes into saturation sooner. Consequently, there are two spikes in voltage for each transition in the drive and the induced voltage is at twice the drive frequency.

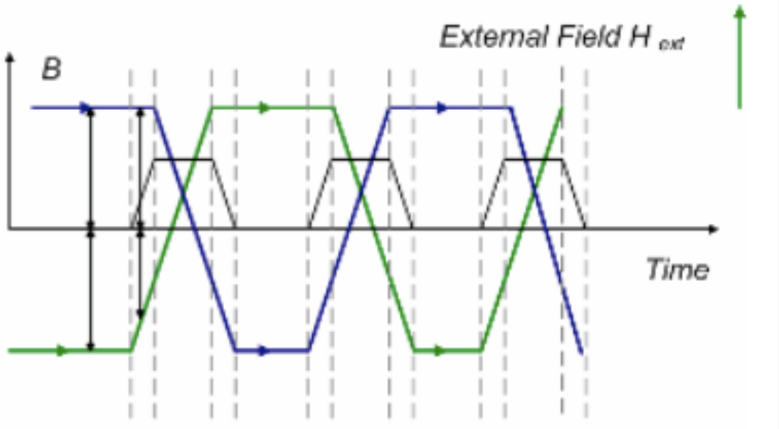


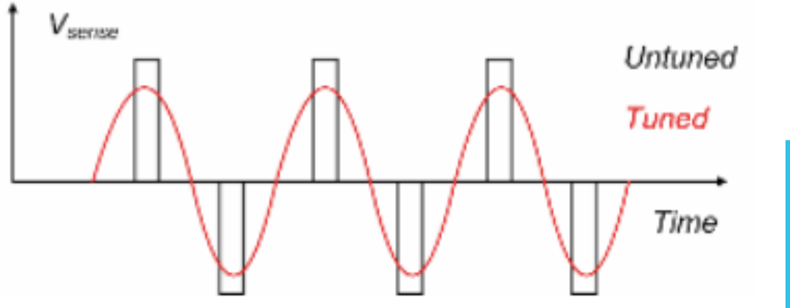


SENSORS: THE MAGNETIC FIELD

- The size and phase of the induced spikes tells us about the magnitude and direction of the external field
- Each ring core can sense the magnetic field in one direction; so to produce a full vector fluxgate magnetometer, three orthogonally mounted ring cores are used







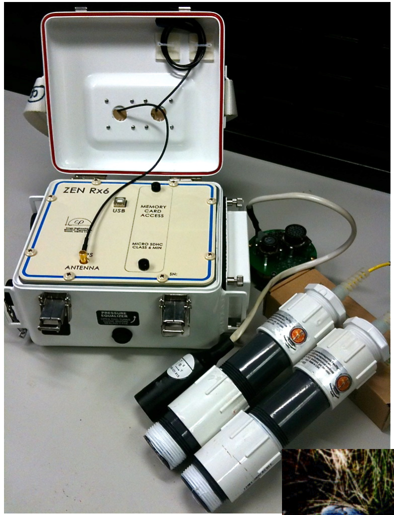
THE NATIONAL GEOELECTROMAGNETIC FACILITY

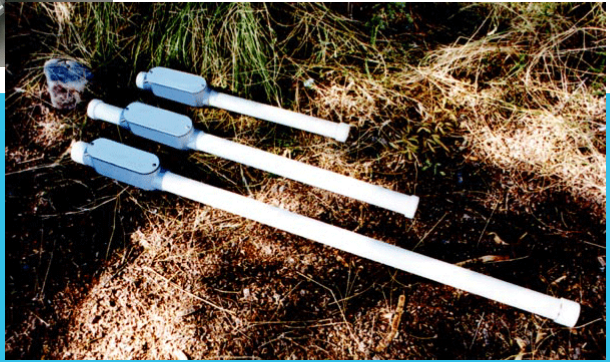
1) IRIS/EARTHSCOPE POOL 2)DOE POOL 3) NGF POOL

Current inventory (94 land MT instruments, 1 Marine combined MT/CSEM/seismic instrument):

26 ZEN wideband/ultrawideband MT receivers:

- 16 Zonge ZEN wideband (0 – 4 kHz) 32-bit resolution
- 10 Zonge ZEN ultrawideband (0 – 1.6 Mhz) 24-bit resolution MT receivers
- 18 ANT4, 30 ANT6, 10 LEMI-014 magnetometers – all owned by OSU



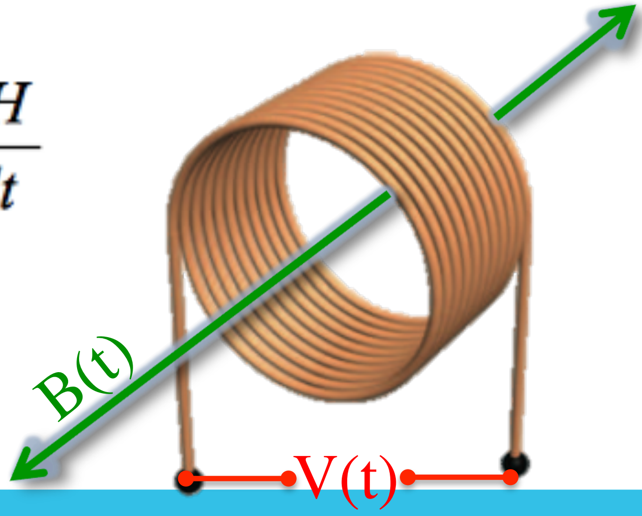


SENSORS: THE MAGNETIC FIELD

The induction coil (or search coil) magnetometer

- Sensitive to time-changes in the magnetic field in a given direction

$$V = -n \cdot \frac{d\Phi}{dt} = -n \cdot A \cdot \frac{dB}{dt} = -\mu_0 \cdot n \cdot A \cdot \frac{dH}{dt}$$



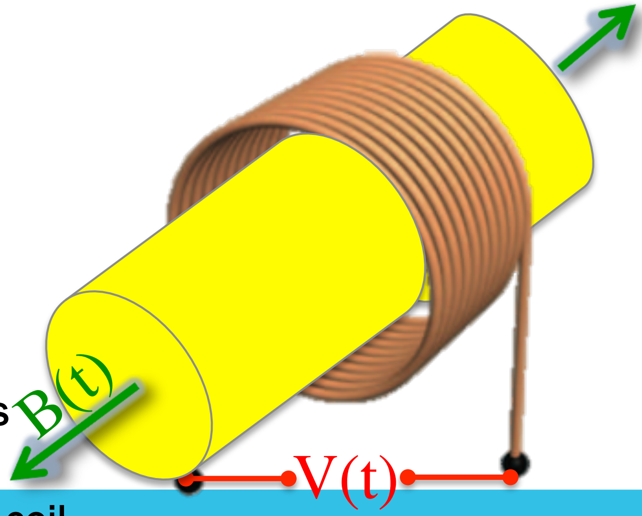
where n is the number of windings of the coil, and
A is the area of the open face of the coil

- It is necessary to integrate V in order to obtain B, rather than dB/dt.

SENSORS: THE MAGNETIC FIELD

The sensitivity of the induction coil magnetometer is greatly magnified by replacing the air gap with a highly permeable magnetic alloy ("ferrite") core. The core acts as a magnetic flux concentrator

$$V = -\mu_0 \cdot \mu_r \cdot n \cdot A \cdot \frac{dH}{dt}$$



where μ_r is the relative permeability of the core material, which can be as much as 10^5 for currently used core types. The product of the two permeabilities above must be adjusted for geometrical factors, that can reduce the effective permeability of the induction coil. Generally long and thin inductors work best.

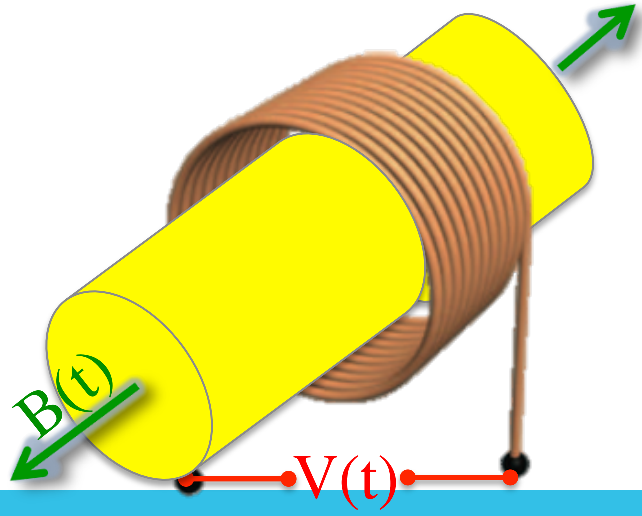
SENSORS: THE MAGNETIC FIELD

As with the fluxgate sensor, the induction coil sensor is sensitive to the magnetic field in only one direction

In order to obtain the three vector components of the magnetic field, three induction coils are required, one pointed in each direction

While the fluxgate sensor is compact, the induction coil sensors can each be as much as 1 m long; this presents challenges particularly when measuring the vertical component of the magnetic field

As a general rule, the longer the physical size of the induction coil, the lower frequency it can sense



THE NATIONAL GEOELECTROMAGNETIC FACILITY

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Current inventory (94 land MT instruments, 1 Marine combined MT/CSEM/seismic instrument):

1 9-channel trawl-resistant ocean bottom wideband CSEM/MT/seismic bottom lander

OSU Multiphysics Bottom Lander

A 1.8-m diameter, trawl-resistant hydrodynamically stable bottom lander equipped with wideband seismometer, magnetometers, electrometers, temperature sensors, optional pressure sensors and hydrophone, chip scale atomic clock

Composite construction to minimize EM interactions

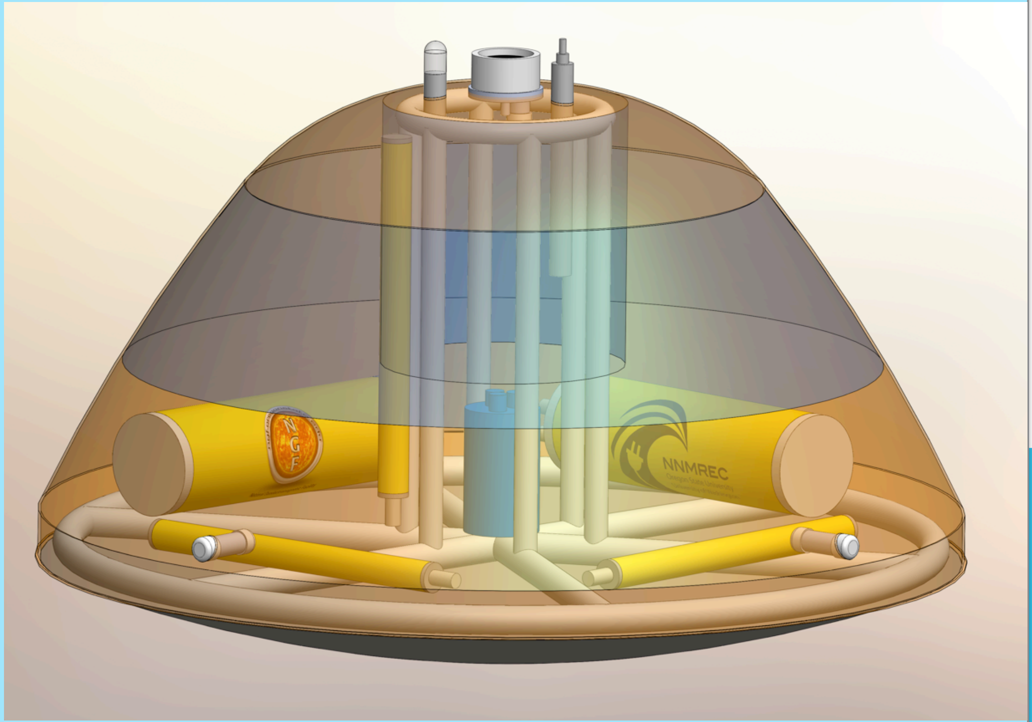
Uses acoustic release for surface recovery; acoustic telemetry of data to ship or buoy

Based on OSU/Zonge Zen/5 32-bit data acquisition system

Up to 4 KHz sample rate on each of 3 electric field, 3 magnetic field, 3 seismic channels

Time keeping accurate to $O(10^{-11})$

Can operate tethered to surface buoy or ship, or autonomously



MT Field Operations

By measuring the electric and magnetic fields at the Earth's surface due to induced electric currents in the subsurface, we determine the electrical resistivity structure of the <u>mid-crust</u> through the <u>upper mantle</u>

MT Field Operations

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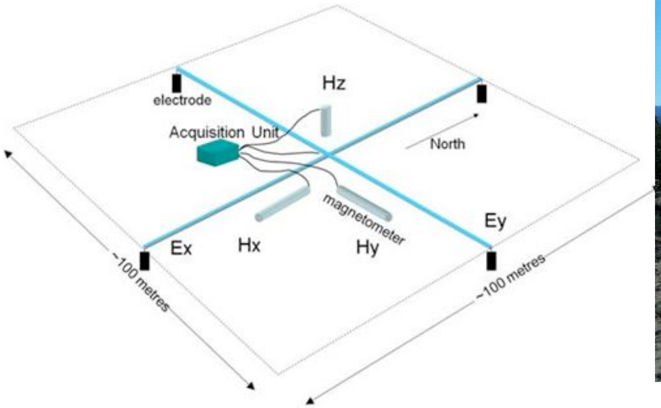
transportable array MT

10^{-4} Hz $\leq f \leq 10^{0}$ Hz



backbone observatory MT

10^{-5} Hz $\leq f \leq 10^{0}$ Hz

MT Field Operations

FlexArray MT – (ultra)wideband
10^{-5} Hz ≤ f ≤ 10^{6} Hz

FlexArray MT can target near-surface, upper crust, as well as mid-crust to upper mantle

Flex Array MT – long-period
10^{-4} Hz ≤ f ≤ 10^{0} Hz

-end-