INITIAL ARTEMIS TIME DOMAIN ELECTROMAGNETIC SOUNDING RESULTS FROM NIGHTSIDE TRANSIENT EVENTS. H.A. Fuqua, G.T. Delory, I. de Pater, R.E. Grimm. 1Space Sciences Laboratory, University of California, Berkeley, CA 94720, (heidi.fuqua@ssl.berkeley.edu), 2Department of Earth & Planetary Science, University of California, Berkeley, CA 94720, 3Department of Space Studies, Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302.

**Introduction:** We use transient events within low altitude nightside ARTEMIS magnetic field measurements combined with forward modeling to constrain the electrical conductivity of the lunar interior. When the Moon is exposed directly to the Solar Wind, spatial and time varying magnetic field signals induce telluric currents within conducting layers resisting the passing perturbation. Isolating geophysical magnetic induction from the plasma effects, such as the diamagnetic current system, is the first step to performing Electromagnetic (EM) Sounding capable of constraining the lateral and vertical distribution of electrical conductivity, core size, as well as derive temperature constraints [3].

Establishing 3D lateral inhomogeneity of the lunar interior is critical to understanding lunar formation and extent of asymmetric surface features such as the nearside Procellarum KREEP Terrain (PKT). To first degree, the crust and upper mantle structure represent cooling thermal boundary layers of accretion, differentiation, and convection dynamics. Lateral and vertical variances of composition provide key constraints on thermal cooling models [5]. The extent of a global magma ocean is detectable in the sharp conductivity contrasts between the PKT and neighboring regions. Moreover, three-dimensional electrical structure of the PKT region could help distinguish its thermal origin and formation processes [3]. In addition, providing lateral constraints on the electrical conductivity of the mantle region, and hence lateral composition and temperature variations, is critical to the current understanding of lunar mantle dynamics and thermal convection processes [3]. EM Sounding provides the possibility to detect the lunar core.

Nightside time domain EM sounding was performed during the Apollo missions using the orbiting Explorer 35 magnetometer and the Apollo 12 Lunar Surface Magnetometer (LSM) [1]. This method required the LSM measurement to be within the lunar wake cavity, measuring the total magnetic field, and Explorer 35 to be well outside of any lunar effects, providing measurement of the upstream driving event within the Solar Wind. This analysis assumed vacuum symmetry neglecting confinement effects within the diamagnetic cavity. Analytical results to a step transient event is demonstrated in Figure 1, showing for the LSM coordinate system (radially pointing up from the surface and tangentially pointing East and North), damping is predicted in the radial component and overshoot in the tangential components.

![Figure 1](image1.png)

**Figure 1.** Dyal et al. [1973] demonstrate EM sounding characteristics to a step input signal showing radial damping and overshoot in the tangential components [2].

![Figure 2](image2.png)

**Figure 2.** Orbital positions for upper and lower probes are shown above in blue and black, respectively. Red indicates location of measurement in Figure 3. Corresponds to the Themis B spacecraft in the Lunar Wake at 200 km altitude, while the Themis C spacecraft at 1.5 x 10^{4} km altitude.

**ARTEMIS Observations:** The ARTEMIS mission consists of two originally THEMIS spacecrafts repositioned to study the electromagnetic plasma environment at the Moon [4]. The spacecrafts are in 26 hour elliptical orbits, and all data is publically available online (http://artemis.ssl.berkeley.edu). Step transient events have been located with one probe close to the lunar surface, as well as within the lunar wake, and the other probe outside of lunar effects. Figure 2 demonstrates ideal sounding geometry. The position of the ARTEMIS periapse passes vary about the lunar equator providing wide coverage of the lunar surface. Due to ARTEMIS varying lunar longitude periapse
passes, lateral constraints on interior electrical conductivity can be determined. This is a large improvement over previous results which obtained a single electrical conductivity profile corresponding to the Apollo 12 LSM location or bulk parameters. Long period time domain sounding will pose a challenge due to the short time frame (less than 30 minutes) of low altitude ARTEMIS periselene passes. In addition, fluctuations within the Interplanetary Magnetic Field are rapidly changing posing a challenge to isolate long period events.

Initial time domain induction signals are presented. ARTEMIS fluxgate magnetometer (FGM) data has been rotated into a similar coordinate frame as Apollo’s LSM, radially pointing vertically up, tangentially pointing north and east. The transient event is time shifted according to probe separation distances and estimated disturbance velocity. Plasma background effects such as the diamagnetic fields and crustal fields are removed. Plotted in Figure 2 is one such example demonstrating radial damping between the upper probe and lower probe measurements. Also good correlation between the predictions made by our forward model (with upper probe data as an input) and lower probe data is shown.

**Modeling:** The vacuum response of the Moon to a spatially uniform time-varying magnetic field has been calculated using the COMSOL Multiphysics 4.3b AC/DC Module (http://www.comsol.co.in/acdcmodule). This is a commercial finite element analysis software that solves the magnetic diffusion equation:

\[ \nabla^2 \mathbf{B} = \sigma \mathbf{\mu}_0 \frac{\partial \mathbf{B}}{\partial t} \]

The upper probe FGM data is fed as an input into the model. This calculation is performed in 3D allowing direct comparison to the LSM coordinate system. The global cartesian coordinates are \((x, y, z)\) centered at the center of the Moon in a Selenographic coordinate system.

The model domain consists of a 4.5 lunar radius cube. The Moon is a sphere of radius \(R_m = 1,738\) km with 3 layers of varying conducting representing a differentiated interior. These layers consist of a resistive crust (depth > 0.7 \(R_m\), \(\sigma = 10^{-9}\) mhos/m), conducting mantle (depth = 0.3-0.7 \(R_m\), \(\sigma = 10^{-4}\) mhos/m), and a highly conducting core (depth < 400km, \(\sigma = 10^{-2}\) mhos/m) [1, 3]. Other conductivity profiles are being studied including a radially varying conductivity profile [3]. The mesh size varies including more elements around the lunar core and increasing outwards. The minimum element boundary length is 422 km in the vacuum and 11.7 km in the Moon. There are approximately 24,595 tetrahedral, 1,648 triangular, 180 edge and 14 vertex finite elements and approximately 105,284 degrees of freedom.

This model in its early stages displays good correlation with the measured lower probe values as shown in Figure 3. Confinement effects are being studied and will be added to future revision of the model. This will consist of a dayside spherical cap and nightside cylinder boundary conditions.

![Figure 3. An initial Radial induction signal demonstrates expected damping characteristics for steep transient events (t=220s). Coordinate system is a local spherical coordinate system based on Themis B orientation.](image)