Analysis and Comparison of Earth and Mars Surface Magnetic Data to Understand Internal Electrical Conductivity

地火磁場對比：解析行星內部電性構造

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Motivations & Objectives

Planetary interior conductivity provides a key way to study subsurface **water content** and **partial melt**. Since high-conductivity regions correspond to fluids or partial melting, analyzing these structures gives important insights into planetary evolution and internal dynamics over geological time.

Using continuous surface magnetic field data recorded at planetary surfaces (Figure 1, KNY station on Earth and InSight lander data on Mars), we can analyze and understand the planets' interior conductivity structures.

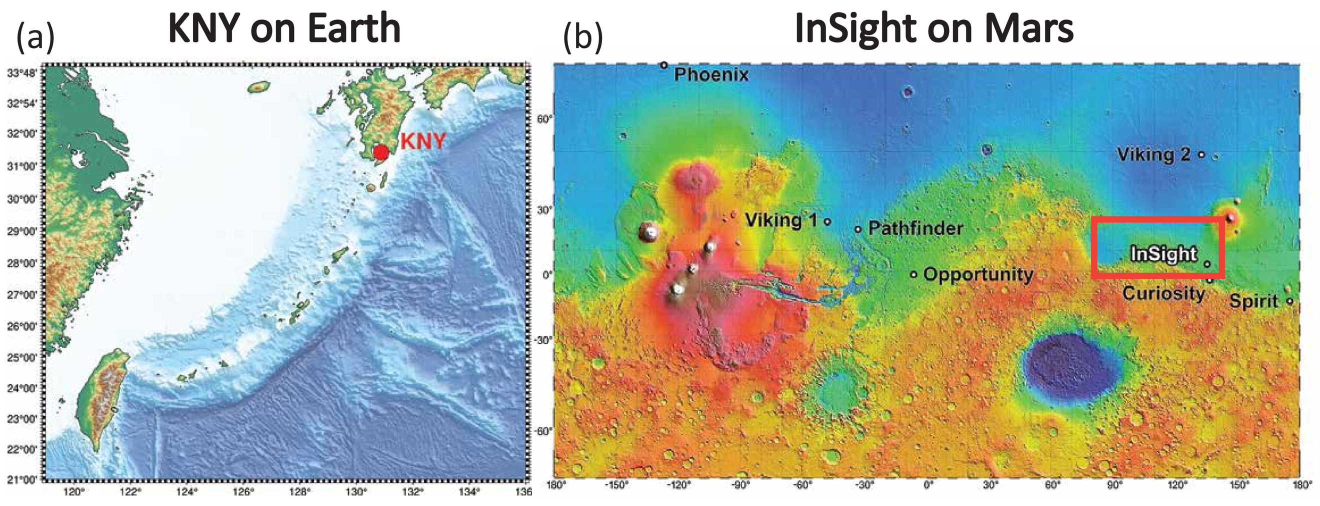

Figure 1. Locations of magnetic field monitoring stations: KNY station on Earth (left) and InSight lander on Mars (right). Mars image credit: NASA/JPL.

Objectives:

- **Compare Earth and Mars magnetic field data** to reveal fundamental differences in planetary surface magnetic signatures.
- **Develop C-response methodology** for electrical conductivity modeling from continuous magnetic data.
- **Investigate Mars' subsurface electrical structure** through forward modeling
- **Assess temporal robustness across different data lengths** despite Mars observational gaps (Figure 2a)

Magnetic Data: Time vs. Frequency Domain

We process raw magnetic measurements by dividing continuous time series into multiple windows and transforming them into the frequency domain (Figure 2).

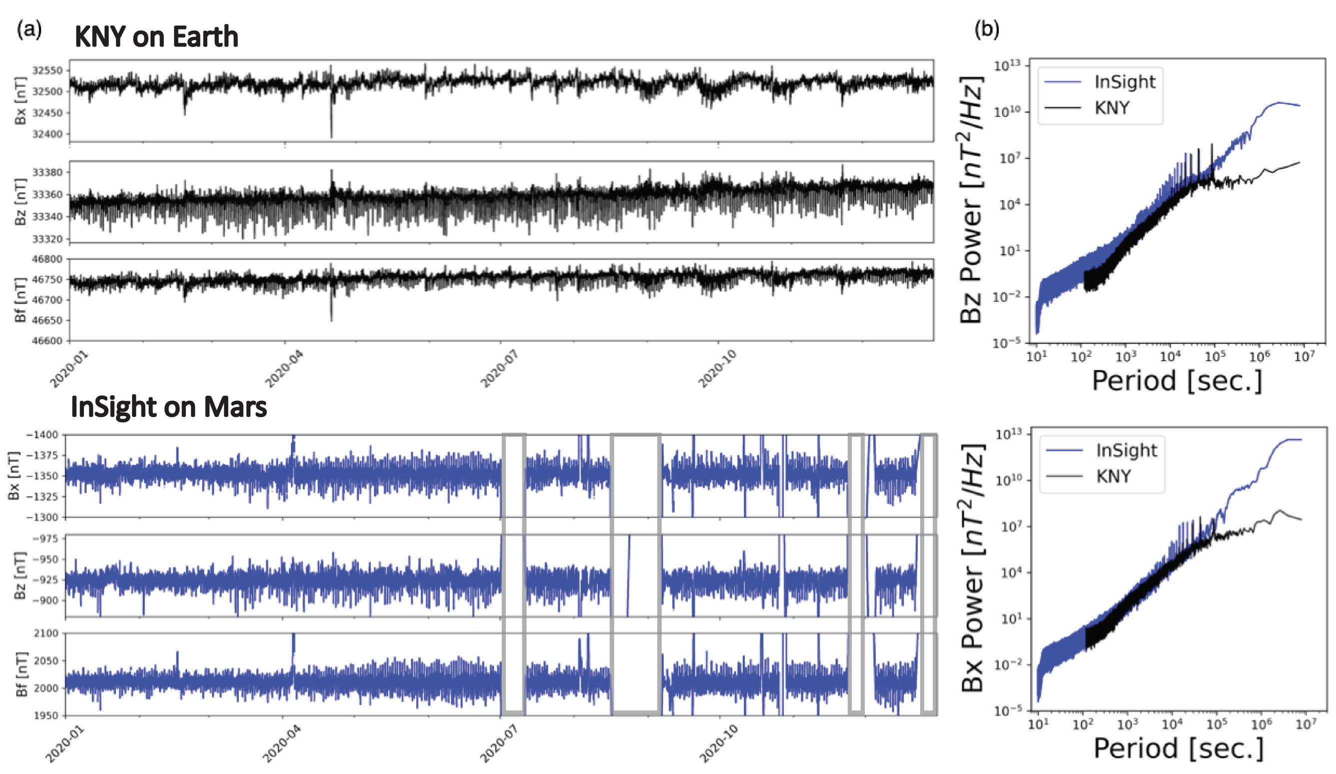

Figure 2. (a) Magnetic field time series (2020, Sol 390–746) showing Bx, Bz, and total field (Bf), with grey boxes marking time gaps. (b) Power Spectral Density (PSD) of Bx and Bz. Black: Earth (KNY); Blue: Mars (InSight).

We calculate the total field intensity (Bf) from three magnetic components. Bx (north) and Bz (down) are specifically used in our data analysis. Earth's Bf values are ~23 times larger than Mars values, reflecting Earth's self-generated magnetic field versus Mars' lack of a global field. In the frequency domain, InSight shows higher PSD values than KNY, indicating stronger temporal magnetic variations..

Deriving Apparent Resistivity: Earth vs. Mars

Since direct measurements of the Martian electric field are difficult to obtain, we make use of the close relationship between electric and magnetic phenomena. By applying the **Geomagnetic Depth Sounding (GDS)** method to magnetic field observations, we calculated the period-dependent **C-response** and converted it into the **apparent resistivity (AR) and phase** to infer the planet's internal structure.

C-response is affected by planetary radius (R) and transfer function. Earth's equation includes co-latitude (θ) due to its intrinsic field, while Mars uses the simplified form without this geometric factor.

$$C_{Earth}(\omega) = -\frac{R_{Earth}\tan\theta}{2}\cdot\frac{B_z(\omega)}{B_x(\omega)}$$

$$C_{Mars}(\omega) = -\frac{R_{Mars}}{2}\cdot\frac{B_z(\omega)}{B_x(\omega)}$$

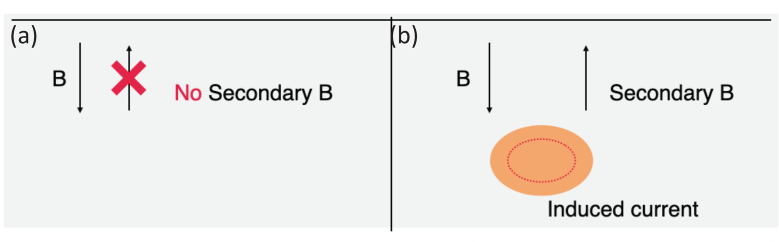

Figure 3. Electromagnetic induction concepts: (a) resistive layer - no secondary field, (b) conductive layer - induced currents generate secondary field.

Transfer functions quantify conductivity effects on Bz/Bx ratios. Resistive subsurfaces produce weak Bz (Figure 3a); conductive layers amplify Bz through enhanced induction (Figure 3b).

C-response values in real and imaginary form are converted to magnitude and phase, providing apparent resistivity (AR) and phase measurements for conductivity analysis.

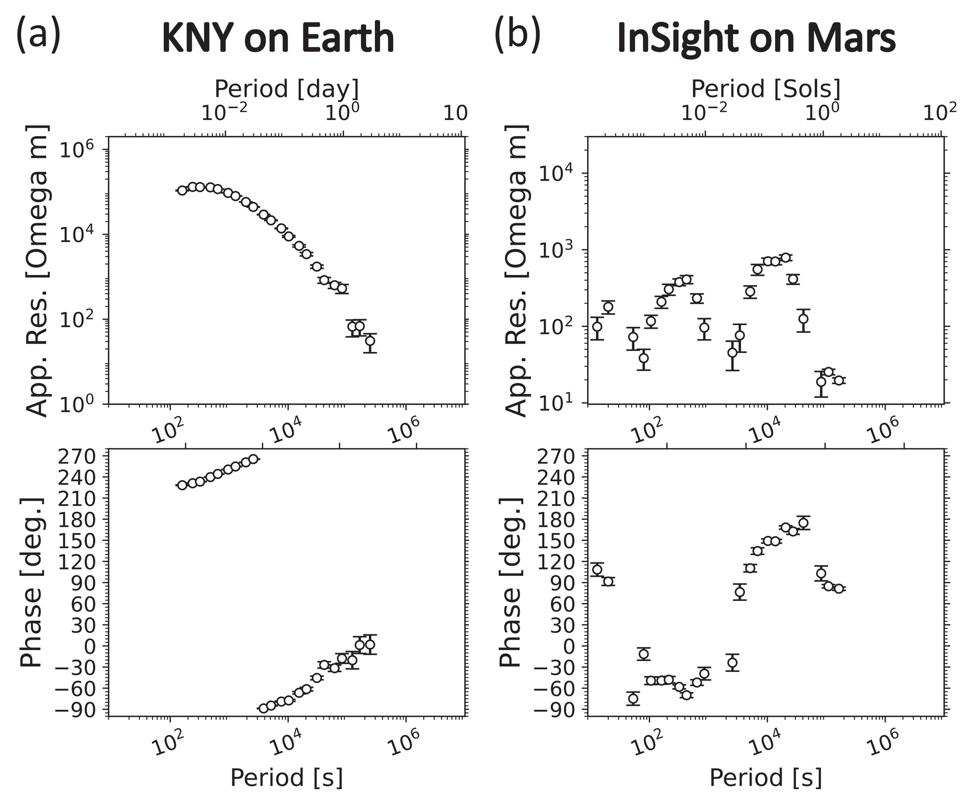

Figure 4. The apparent resistivity (AR) values and phase vary with period at (a) KNY station and (b) InSight.

KNY station (Figure 4a) shows apparent resistivity decreasing with increasing period, while InSight (Figure 4b) exhibits AR values varying between 10–1000 Ω·m.

Phase values show strong variations from the ideal 45° in both datasets, possibly due to topographic and ocean–continent effects at KNY, while Mars variations remain an open question for future study.

Mars Apparent Resistivity & Forward Modeling

We compare InSight apparent resistivity we got with 3 existing Mars studies (Figure 5a):

- Grimm (2002) - Theoretical modeling predictions
- Ruedas & Breuer (2021) - Geodynamic models (we forward AR from their conductivity structure)
- Civet & Tarits (2014) - Satellite-derived models (we forward AR from their conductivity structure)

InSight observations at short periods (<3000s) fall between earlier model predictions, enabling constraints on InSight's subsurface electrical structure.

We then propose 3 models (Figure 5b):

- the shallow-variation model,
- the deep-variation model, and
- the low-conductivity model.

We forward-modeled the theoretical AR values from these models as shown in Figure 5a. The deep-variation model best fits our calculated AR values.

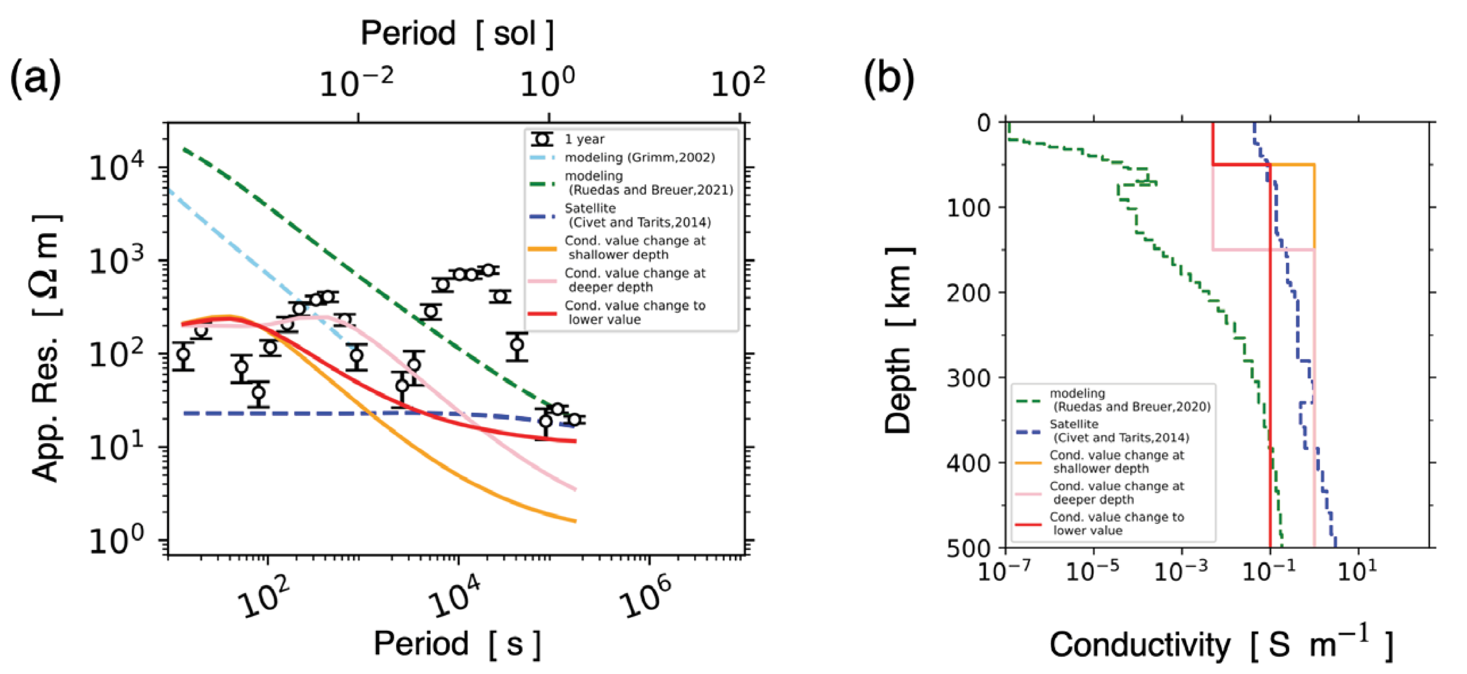

Figure 5.(a) Mars apparent resistivity vs. period. Black dots: InSight data. Dashed lines: existing models. Solid lines: our three proposed models. (b) Conductivity profiles vs. depth.

Temporal Robustness Assessment

We evaluated three InSight magnetic field datasets from 2020 (Sol 390-746) with varying durations: one year, first two months, first two weeks assess C-response consistency across different observation periods (Figure 6)

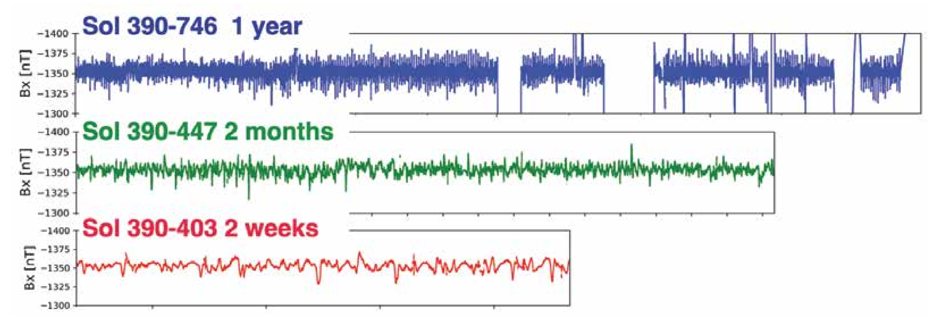

Figure 6. InSight magnetic field datasets of different durations. Sol 1 = first mission day. Time axis not to scale.

Results show that (Figure 7) while longer datasets enable better deep structure resolution through increased window stacking, short-period analysis remains robust with only two weeks of observations

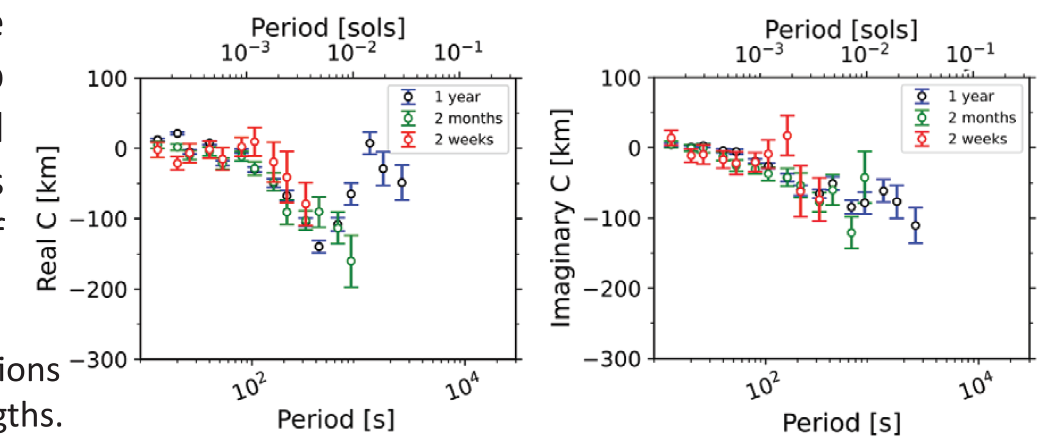

Figure 7. C-response functions from different InSight data lengths.

Key Points & Future Perspectives

- Successfully applied Geomagnetic Depth Sounding (GDS) to Earth and Mars magnetic data, deriving period-dependent C-response functions and calculating apparent resistivity for subsurface electrical characterization.
- Forward modeling of Mars data provides preliminary insights into InSight landing site subsurface structures, establishing a framework for future noise-corrected analysis.
- Temporal robustness analysis demonstrates consistent results across varying InSight data lengths, validating our methodology's reliability for planetary magnetic studies and informing Taiwan's upcoming lunar mission planning.

References & Acknowledgements

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