INSIGHT FLUXGATE MAGNETOMETER DATA CALIBRATION ASSESSMENT AND IMPLICATIONS

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Overview: The InSight Fluxgate magnetometer (IFG), part of the Auxiliary Payload Sensor Suite (APSS), serves the primary purpose of monitoring magnetic fields to assist seismic investigations of Mars. It is the first magnetometer deployed on the surface of the planet, and therefore provides a unique opportunity to use magnetic field data to probe Mars' interior, ionosphere, and interactions with the solar wind [1].

Because the primary function of IFG was not science, the spacecraft and instruments did not undergo a magnetic cleanliness program. Thus measurements of magnetic fields include contributions from both natural (i.e. martian) and lander sources [2]. In order to accurately identify natural variations it is necessary to assess potential sources of noise from lander activity and the extent to which the implemented data calibrations capture these. Here, we address the following questions: How accurate are the models of temperature and solar array current used in the calibration process and how do these affect the resulting magnetic signals? Are there remaining lander signals, in particular ones that can that affect the data systematically?

Here, we briefly summarize the calibration of IFG data (see [3] for details) and describe the contributions of diurnal variations in lander currents and temperatures. We assess the models used in estimating the associated magnetic field corrections, as well as signals generated by various lander activities.

Ground Calibration: IFG data, reported in raw data numbers at sampling rates of 0.2 - 20 Hz, are first converted to physical units (nT). This initial step, based on pre-launch calibrations, depends on the IFG electronics and sensor head temperature (ET and ST, Fig. 1a,b). Temperatures are required at the times of magnetic field measurements to convert the raw data to nT.

ST was initially reported every 100 s, but increased to every 1 s after sol 182, when the IFG continuous data rate was increased from 0.2 Hz to 2 Hz. Prior to sol 182, model temperature curves were fit to the data using polynomials. For later sols linear interpolation was used to provide the required temperature values.

ET was only reported approximately three times per sol up to sol 350. Since then ET data have been available every 1000 s. For the first 350 sols of data a running polynomial fit of the Payload Auxiliary Electronics temperature (PAE T-0014) was used as a proxy for the infrequently sampled IFG ET [3]. The model ST and ET are then used to calibrate the IFG data using the pre-launch thermal calibration [4,5]. After conversion, the spacecraft field determined from ground testing is then subtracted from these values (549, -434, 26.5 nT in the spacecraft frame).

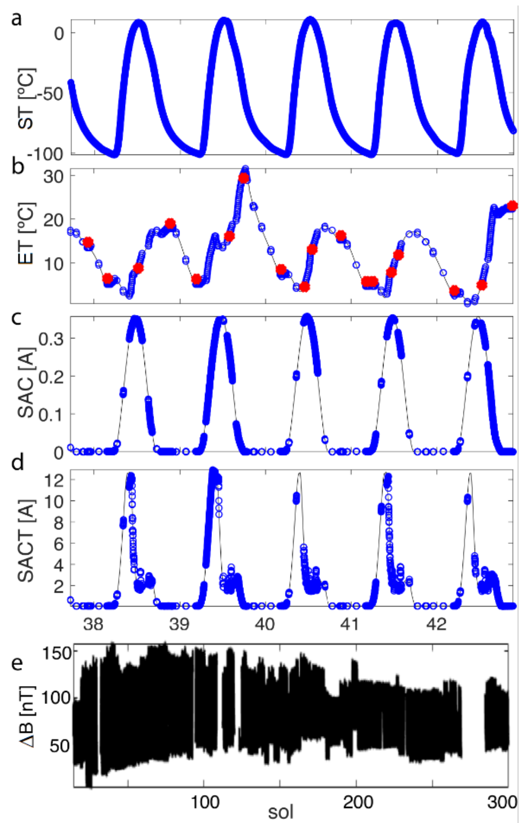

Figure 1: a-d) Data (blue dots) and models (black lines) of Sensor Temperature (ST), Electronics Temperature (ET), Fixed Solar Array Current (SAC), and Total Solar Array Current (SACT) from sols 38-42. Red dots in B are ET data while blue are the proxy temperature. e) Magnitude of magnetic field correction (ΔB) for the first 300 sols.

Post-Landing Calibration: Further corrections are needed after the initial calibration as large amplitude, daily variations remain in the magnetic field that are correlated with temperature and solar array currents.

Solar array currents are provided via four channels corresponding to fixed (E-0771, E-0791) and total (E-0772, E-0792) currents. These are not provided continuously and are characterized by long data gaps (Fig. 1

c,d). Mars local time models have been developed for these currents. The fixed solar array current (hard-wired currents in each solar array) has a repeating shape and the available data are well fit by the model (Fig. 1c). The total solar array current is the sum of the remaining current, with no information regarding its association with either individual solar array. The infrequent data is characterized by high noise during the martian day (10 am – 4pm), with the daily shape also changing over the mission. Thus, the model requires careful sol-by-sol hand processing to fill in the data gaps and capture observed sharp changes as accurately as possible (Fig. 1d).

Removal of the remaining IFG signal that is correlated with the temperatures and currents is performed by calculating and subtracting a linear fit (ΔB) to the model temperatures and currents (Fig. 1d, [4,5]). The changing nature of the lander conditions (both seasonal and operational), means that the coefficients for the fit must be frequently recalculated. The magnitude of the resulting corrections is on the order of ~50 nT at night and ~150 nT during the day (Fig. 1e).

Calibration Assessment: To assess the calibrations, we first systematically compare differences between available temperature and solar array current data and models for the first 300 sols. The model ST represents the ST data very well, the correlation coefficient between the two is $r = 0.98$. Despite the sparse proxy ET data, the fit of the model ET to the proxy ET is good ($r = 0.99$). The quality of the proxy's description of the actual ET data is important and currently unknown, but future work will assess this using the increased data rate since sol 350 (Nov 20, 2019). Due to the smoothly-varying nature of the fixed solar array current, the model SAC fits well despite data gaps. The least well-captured channel is the model SACT which differs most from the total solar array current data in late morning and mid-afternoon.

Lander Activity: Lander activity is clearly associated with induced IFG signals. Four lander activities, lander-on, lander communication, RISE communication, and arm operation, were found to correlate in time with characteristic magnetic field perturbations. These short duration signals are often up to 10 nT in amplitude, and occasionally larger.

Lander-on commencement is followed by an initial spike in all 3 magnetic components. Sequences of arm operation are often seen with sawtooth signals and several of the most noisy sols have unusually high arm activity. Lander and RISE communication are both associated with jump or drop disruptions in all components (Fig. 2a).

As well as aperiodic perturbations, lander activity can introduce persistent signals that systematically affect measurement. Communications contribute recurring signatures at consistent local times (RISE: 6/7 am and 3/4 pm, lander: 6/7 am and 6/7 pm, Fig. 2b).

Step removal algorithms applied to the data have addressed some of these artifacts, but their variable nature makes a general approach difficult to implement. It is thus necessary to consider lander activity for science objectives that require quiet data or analysis and interpretation of small amplitude, short-duration signals.

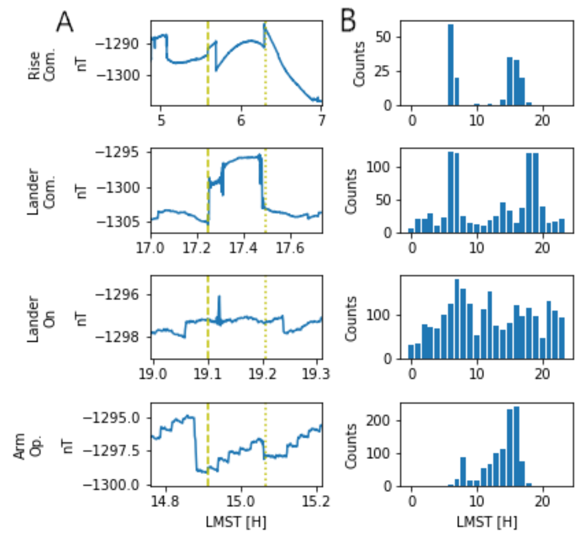

Figure 2: A) Characteristic magnetic signals (North component of field shown) associated with lander activities (yellow dashes and dots are start and stop of activity respectively). B) Frequency of lander activities over the first 300 sols vs. local time.

Implications: Lander signals cause both short aperiodic perturbations and periodic signals during regular times in the day. The models used in the calibration match the available data well, except for the model SACT which differs most from the data in late morning and early afternoon. Assessment of how well the proxy ET captures the actual ET has not been possible until now. A planned increased cadence in the total solar array current sampling should also allow better representation of the high frequency variations by the model SACT. These advances will result in improved calibrations of the IFG data systematically in the late morning and early afternoon, as well as improved estimates of the effects of aperiodic lander activities on the measured field.

References: [1] Banerdt W. B. et al. (2020) *Nat. Geosci.*, subm. [2] Mittelholz A. et al. (2017) *J. Geophys. Res. Planets*, 122, 1243. [3] Johnson C. L. et al. (2019) *Nat. Geosci.* subm. [4] Joy S. P. et al. (2019) *PDS Archive*. [5] Joy S. P. and Rowe K. (2019) *PDS Archive*.