Magnetometer Processing Software for Space Weather Follow-On Mission

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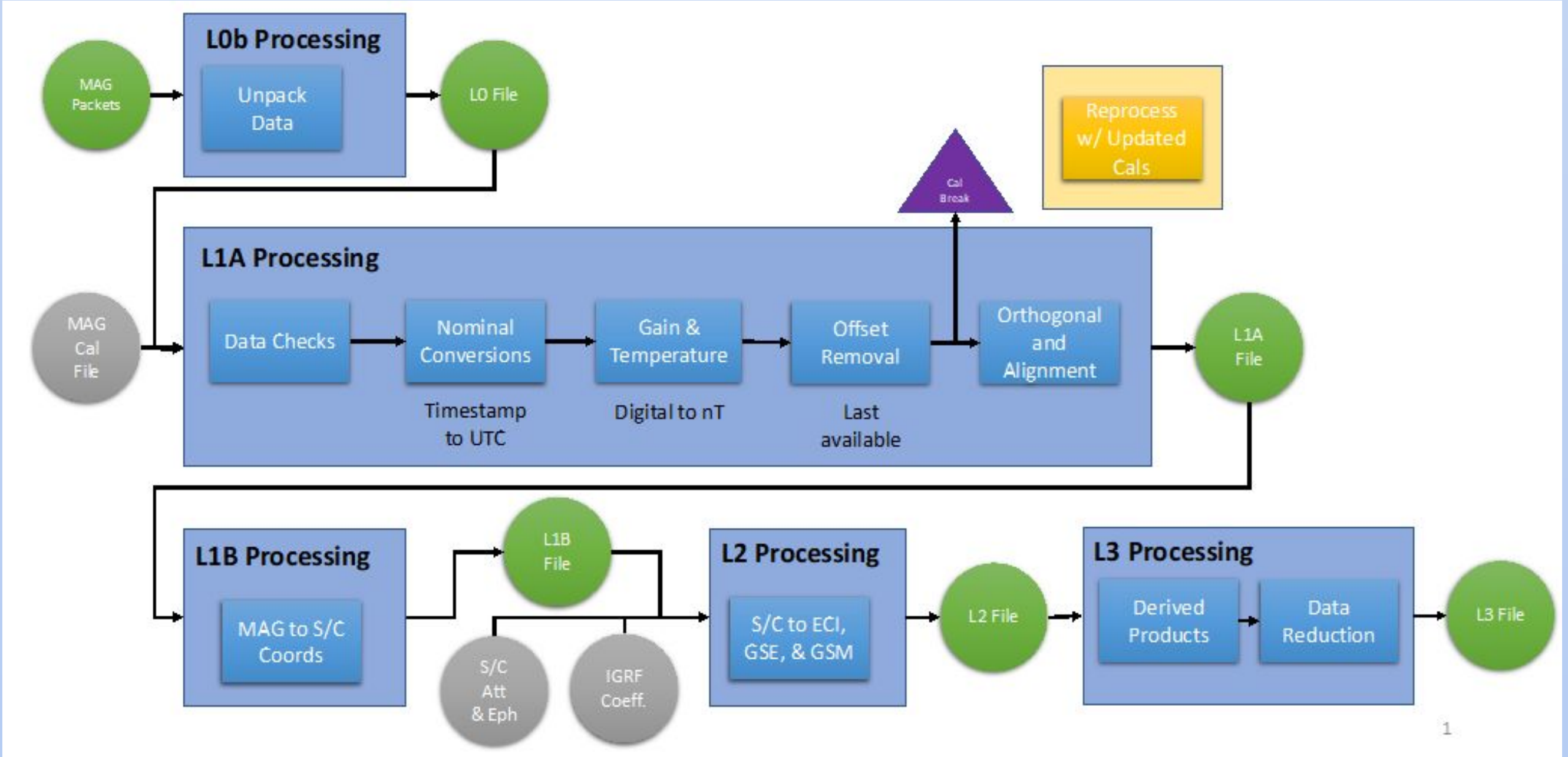
Introduction

The sun produces "space weather" which can potentially harm power grids, disrupt communications, and block navigation systems like the GPS. Any industries which rely on these technologies can be impacted. Space Weather Follow-On, or SWFO, will be a NOAA environmental satellite used to monitor the sun's activity. SWFO will be used as a sentinel whose observations will reduce the response time to harmful space weather events from our sun, such as coronal mass ejections and solar flares.

We present ground software for processing the magnetic field observed by the SWFO spacecraft. The magnetometer is one of a suite of instruments used to measure the solar wind and the magnetic field originating from the sun. Computers on the SWFO spacecraft will integrate, encode, and transmit instrument readings back to Earth. Our software starts there and deals with the data and measurement conversions. The software converts raw data from the satellite into a timestamped series of measurements of the magnetic field. The conversions comprise data cleaning and coordinate conversions. The final dataset is important as calibration of instruments, input for computer models, and for real-time forecasting of space weather.

Data Processing Flow

Our software begins with readings from the magnetometer [1], that are represented in a CDF file format. This file contains encoded packets[8][9]. We read different attributes of the data, after cleaning each part for missing values and outliers. This cleaned data is then plotted against time, along with the errors for our calculations. The resulting data is and historical sequence of true magnetic field vectors. [6]



Packets to fields. The flow of data conversions, starting from encoded packets generated by the spacecraft -- into magnetic field vectors in the coordinates of labs on Earth [4]. *Offset Removal* will use the output from our offset determination algorithm.

L0b : Communications packets sent from spacecraft.

L1A : Magnetic field measurements with time stamps, including gains, offset removal, and orthogonalization.

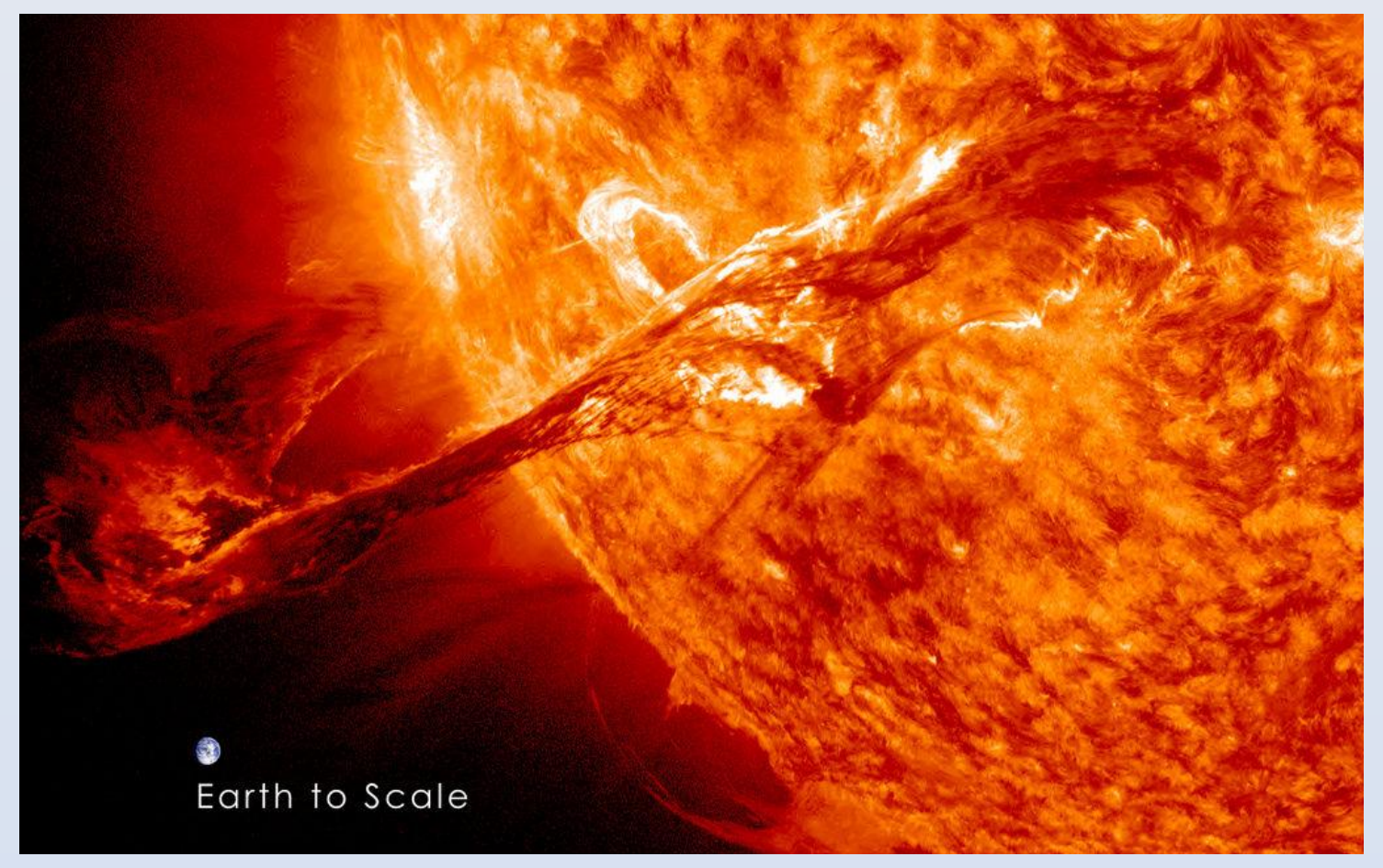
L1B : Magnetic fields in physical units with ground calibrations applied, now in Earth Centered Inertial (ECI) coordinate form.

L2 : Field measurements, at 1 second cadences, in Geocentric Solar Ecliptic (GSE) coordinate form.

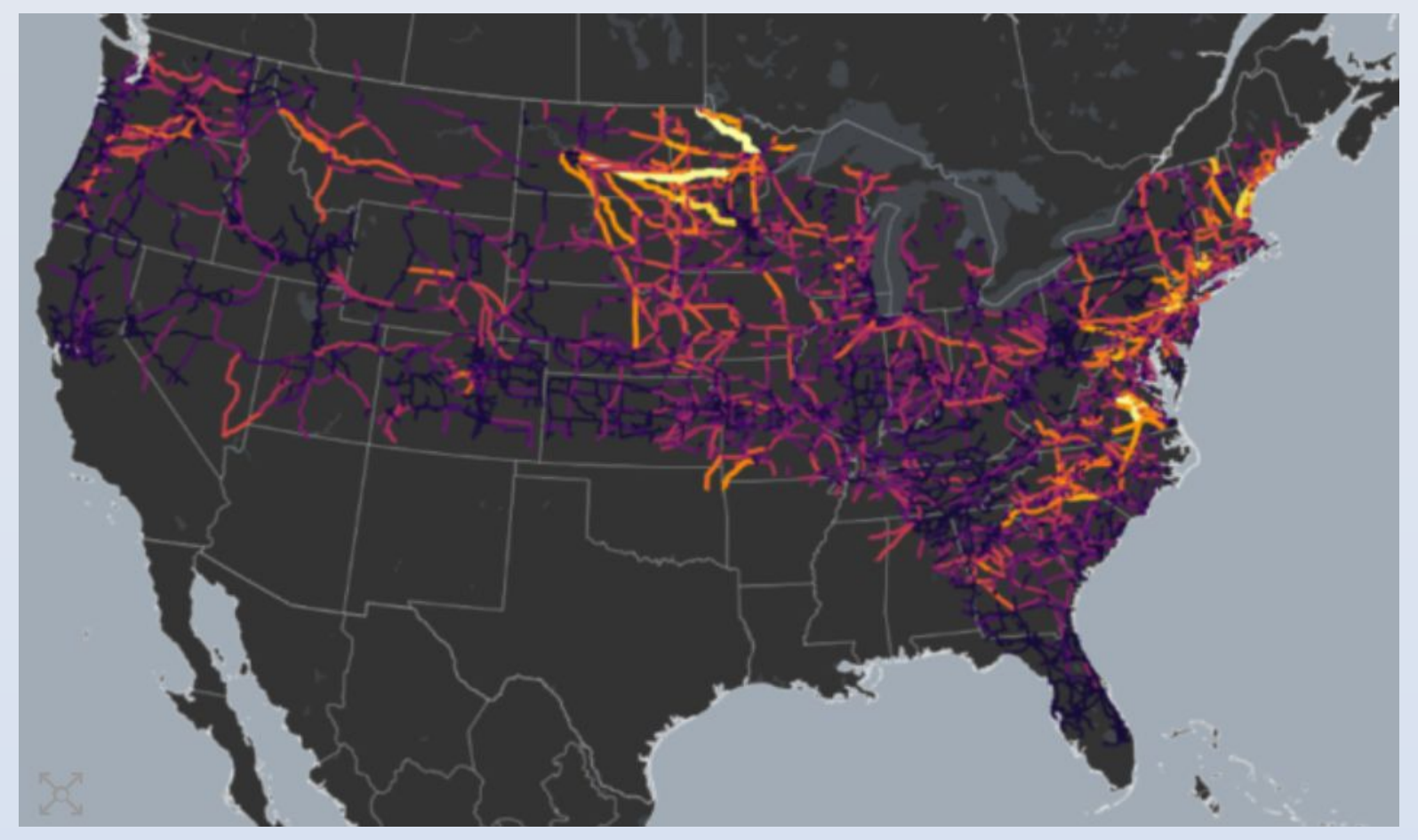
L3 : Derived products. Polar coordinates added to archive. Data suited to space weather forecasting and website archives.

Space Weather

Location of Satellite in Space. SWFO holds a position upstream of the magnetic field. "Lagrange-1", which is a location between the Earth and the Sun where the gravitational pulls are equal between them.



Coronal Mass Ejection. A release of plasma and a magnetic field from the sun. CME's can be massive and travel extremely far.

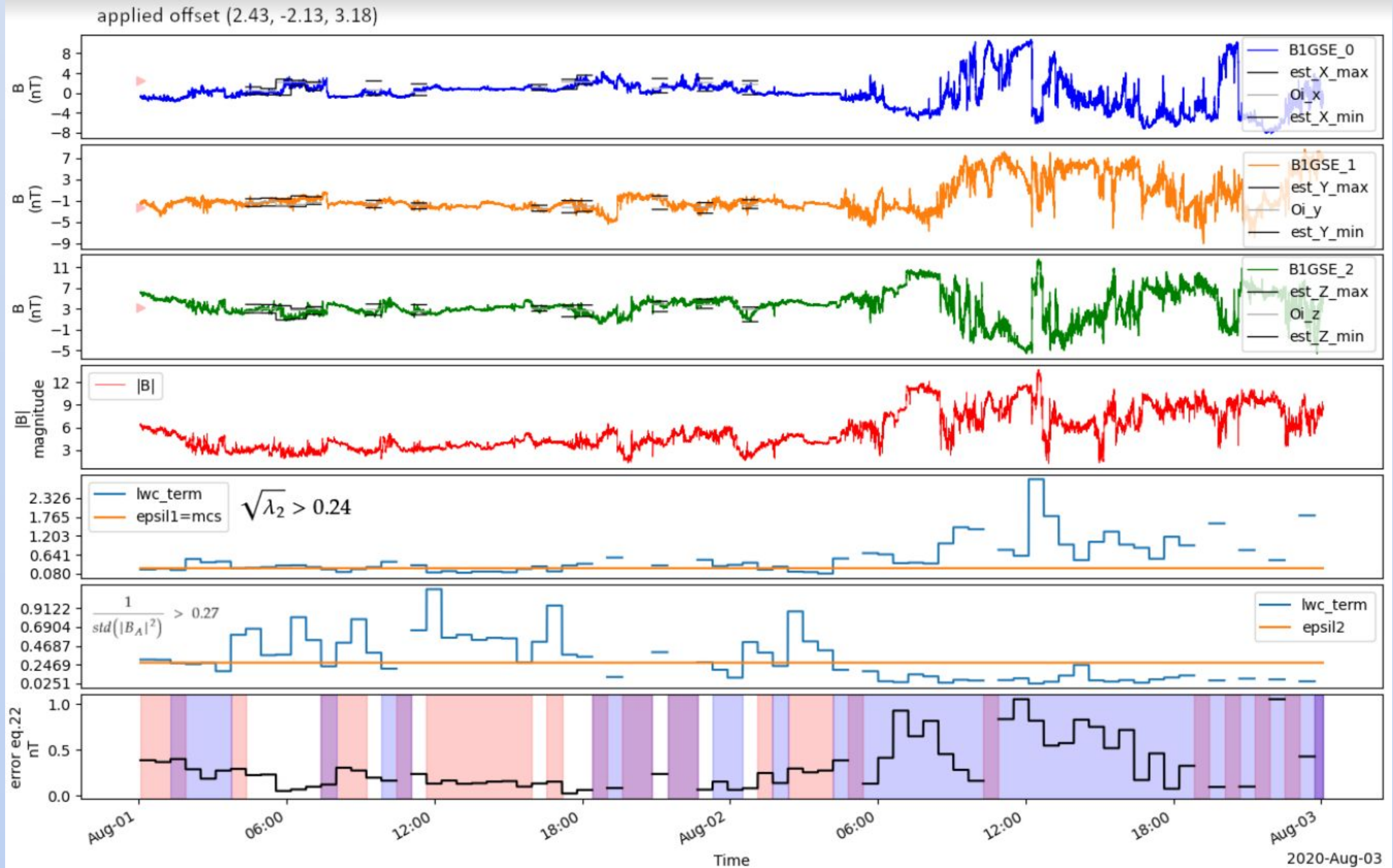


Potentially Impacted Power Grids. The lines on the map represent power lines that would potentially be affected by a Coronal Mass Ejection (CME), where the lighter the line, the higher the risk.

Meet The Team

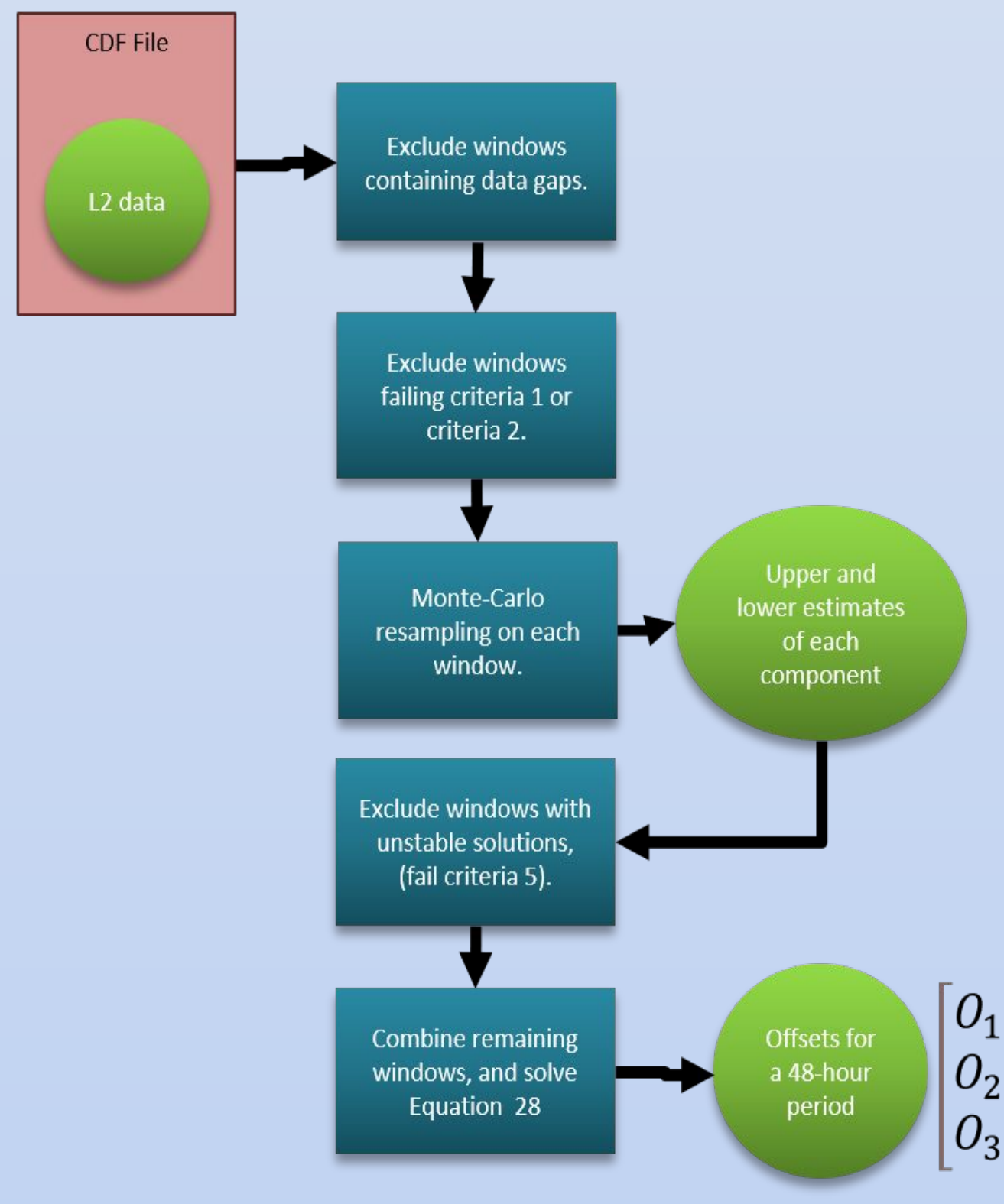
- Stephen Horn: Senior in Computer Science
- Quinn Graham: Senior in Computer Science
- Ezekiel Emstad: Senior in Computer Science
- Matthew Argall: Research Scientist II

Offset Determination



Calibration of the magnetometer is initially performed on the ground. After launch, calibration must continue throughout the lifespan of the mission while the magnetometer is 900,000 kilometers away. This difficult problem has a solution if offsets could somehow be determined from magnetic field data alone. This is possible with sufficiently clever software [5][7].

Window Selection. Three components of the magnetic field vector <**Bx** , **By** , **Bz**> . The field magnitude in red |B|. Windows are excluded that fail selection criteria. Criteria 1 requires some independent fluctuation of the field components within a window. Criteria 2 ensures small deviation in the field magnitude. Taken together they identify windows where solutions are most accurate [5]. Those are intervals in time in which the magnetic field is undergoing a pure rotation. Selected windows appear only in white bars at the bottom. The thick black line is the error in the solutions, lower is better.

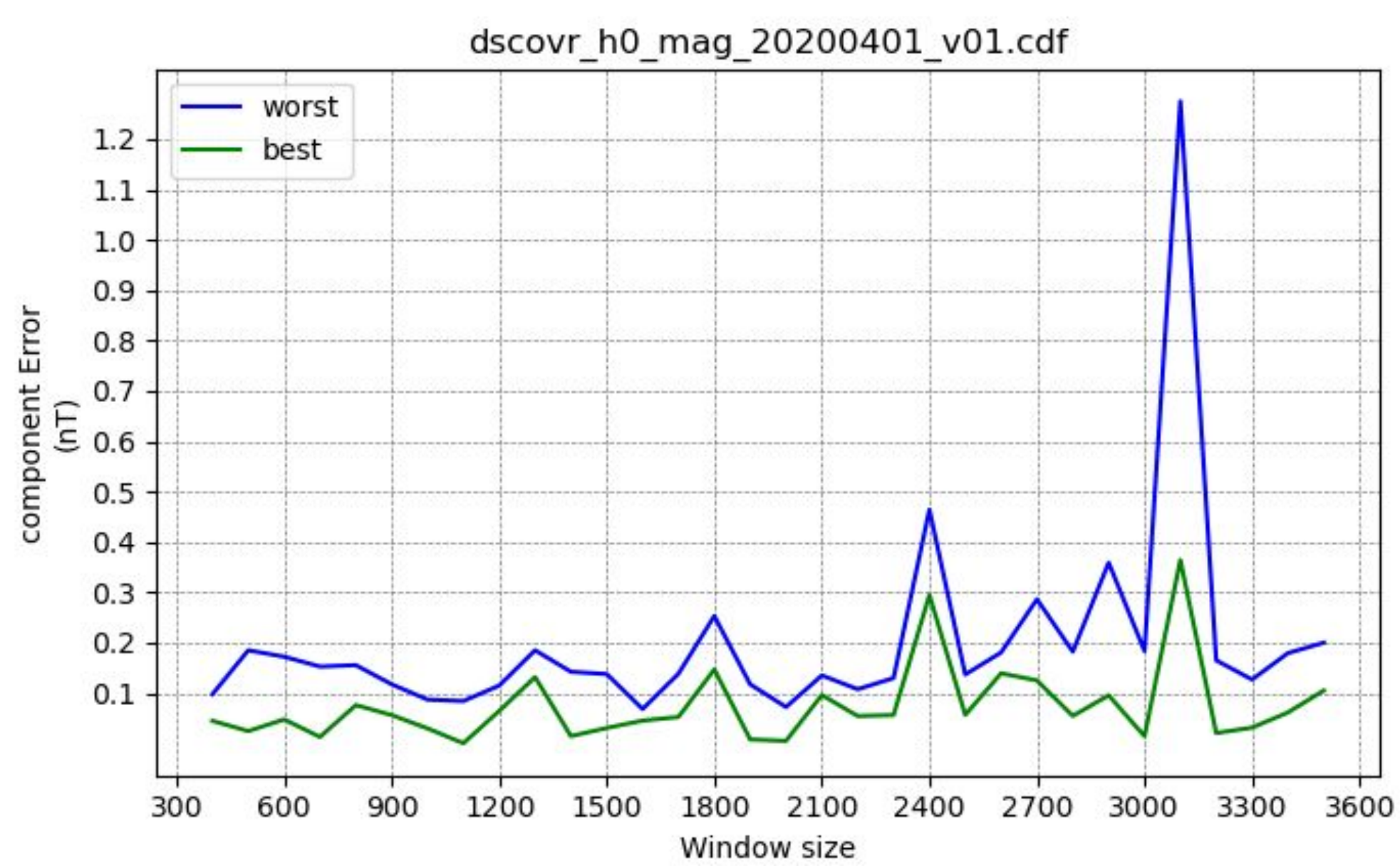


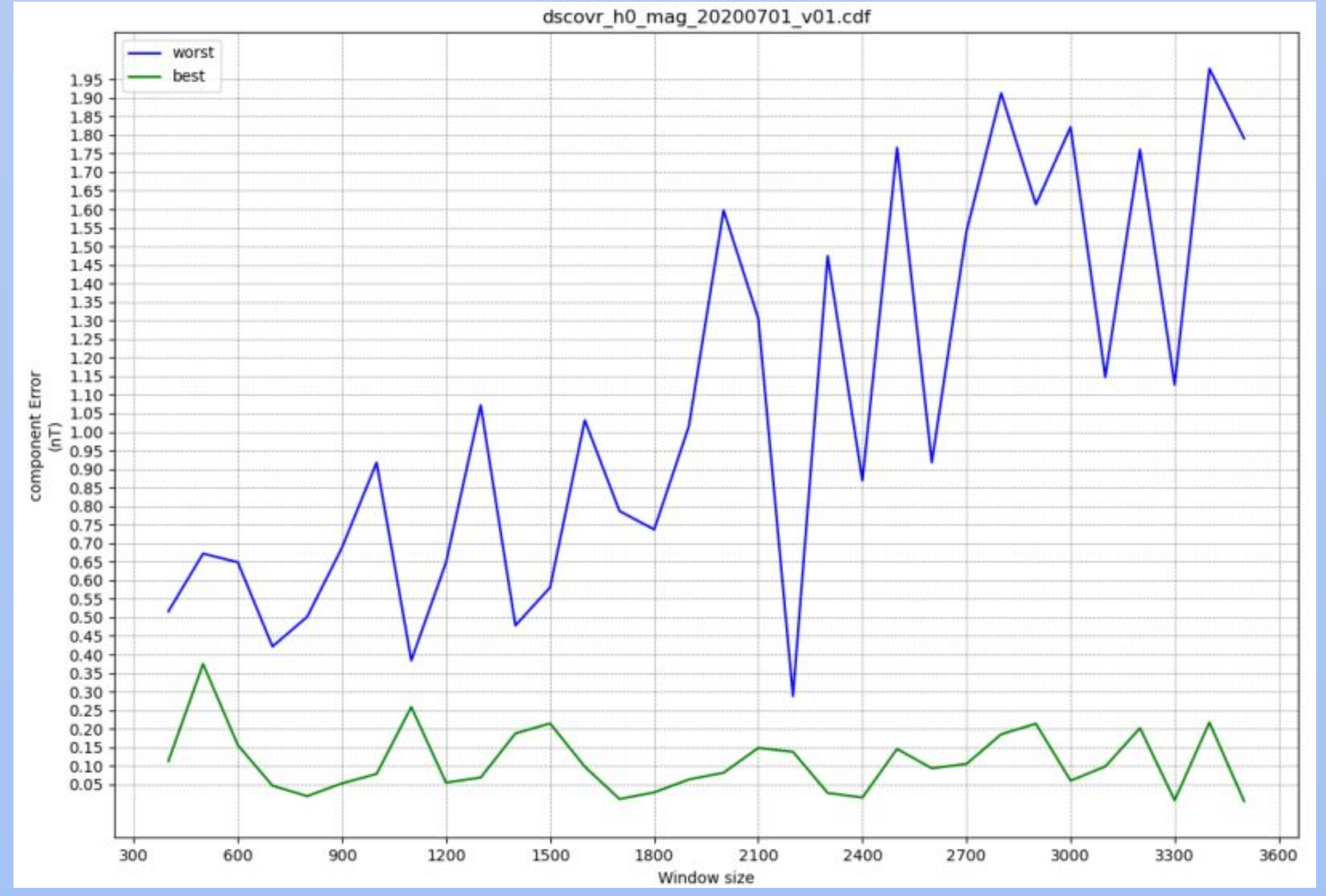
Results

NASA Goddard website hosts an archive of interplanetary magnetic field data collected by the spacecraft DSCOVR [3]. Our system downloaded this data with ranges given by a user interface. This allowed us to deploy our algorithm on true interplanetary magnetic field data..

After excluding failed windows, the remaining windows from a 24-hour period are combined and a matrix equation is solved. Our method inferred a final offset of **<2.393 , -2.043 , 0.150>** versus the applied artificial offset of **<2.43, -2.13, 0.18>** for the day of April 1st, 2020 -- and an inferred final offset **<2.377, -2.817, -0.029>** for the day of July 1, 2020. Errors are well within the allowable range of 0.3 nano-Tesla.

Component errors as a function of window size.
April 1 (below) and July 1 (right)





Conclusions and Going Forward

The software will be deployed on the SWFO Satellite itself, which is set to launch in 2024. NOAA Weather Science Engineers will communicate from the ground to the satellite to receive the data produced by our software, then use it to make calculations and future predictions. [1]

The software has a dedicated installer, so future developers and maintainers can easily set up the software to be run on their own machines. The code base has been designed in such a way to make it easy to add new functionality using existing recorded data, so hopefully in the future it will be improved and expanded!

References

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