Rick Saltus, Arnaud Chulliat, Annette Balmes, Jordan Schweizer
CIRES Geomagnetism Team
Richard.saltus@Colorado.edu

Crustal Magnetic Anomaly Maps and Models for Alternative Navigation

Introduction

Magnetic navigation (MagNav) is an emerging technology that can provide positioning information when GPS is unavailable. GPS may be unavailable due to jamming, in underwater environments, in indoor locations, or in other situations with signal may be unreliable. MagNav operates by matching magnetic sensor measurements in a moving platform to detailed magnetic maps and/or models. For this system to work effectively, high-quality maps/models, accurate sensor measurements, and optimum navigation algorithms are essential. Currently, MagNav is still in the prototype stage, although its feasibility has been demonstrated in a number of tests, both by government and private industry. The ability to navigate in GPS-poor environments is essential for military and private navigation.

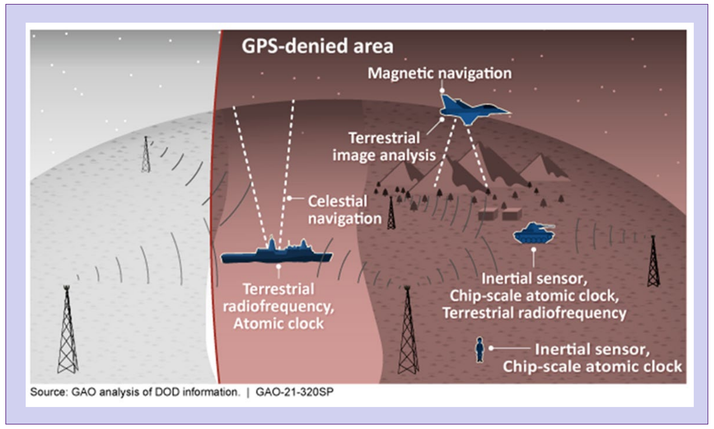

Figure 1. GPS may be unavailable for natural reasons (for example, underwater), or it may be purposely denied through jamming or system destruction. A wide variety of alternative navigation options (alternative positioning, AltPnt) are under development.

Data, maps and models

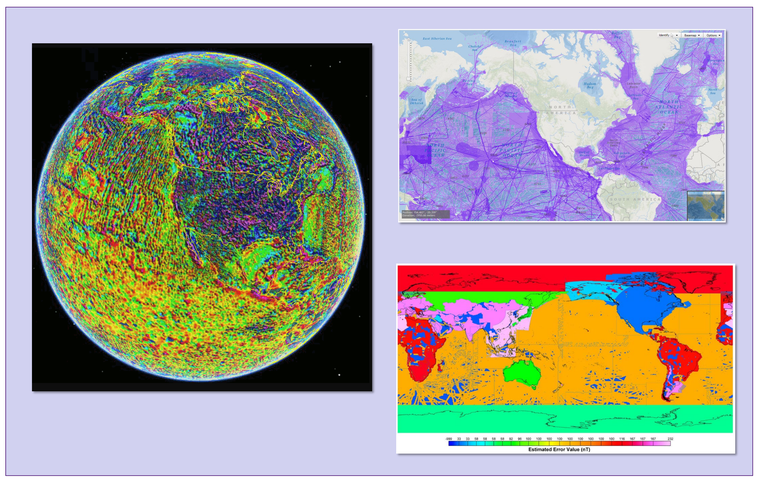

Figure 2. The magnetic field variations (aka "anomalies") caused by the heterogeneous distribution of iron minerals (primarily magnetite) in the Earth's crust can be used a reference for navigation.

Research

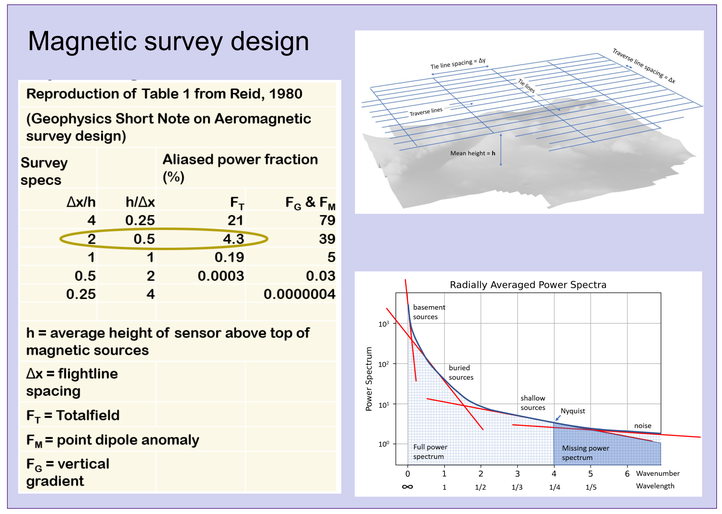

Figure 3. The 1980 survey design analysis by Reid is still a "go to" reference for the lay out of modern aeromagnetic surveys. We have worked up an updated analysis with emphasis on surveys to support alternative navigation (Saltus et al., in review).

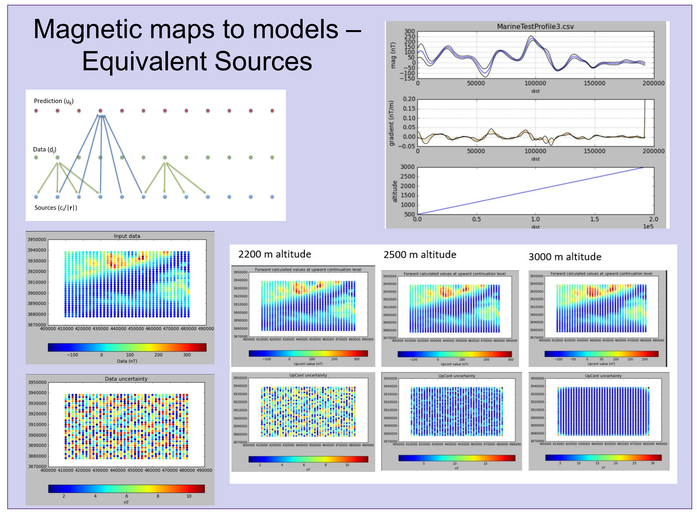

Figure 4. Alternative navigation systems require estimates of the total magnetic field in real time along the predicted flight path. Interpolation from "flat maps" is the current standard, but is not optimal. We are developing new methods for encoding magnetic map information into a model framework that will allow for efficient updates, permit direct queries, and include estimates of model uncertainty.

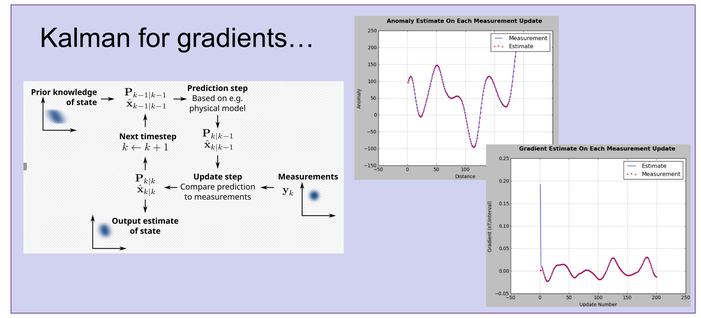

Figure 5. Navigation filters are particularly sensitive to the along and cross track gradients in the crustal magnetic anomaly field. Our current research is testing a Kalman filter for state estimates of these gradients (with associated uncertainty) from inquiry of the equivalent source models.

Conclusions

- The ability to navigate successfully in challenging environments (especially in the absence of GPS), is critical to safe operation in a variety of settings, from civilian to military.
- Indexing location to the patterns in the Earth's magnetic field, so-called "MagNav", offers a valuable contribution to overall positioning and navigation.
- MagNav has been demonstrated as viable in controlled experiments using high quality modern aeromagnetic survey data and magnetically "clean" aircraft.
- A key challenge for broad application of MagNav is the construction of trustable magnetic field reference maps and models.
- The CIRES Geomagnetism team is conducting active research in this field (with support from the National Geospatial Intelligence Agency – NGA – and the Office of Naval Research – ONR).
- We are also working closely with the Air Force Institute of Technology (AFIT), the Air Force Research Lab (AFRL), the MIT Lincoln Lab (MITLL), and private industry such as LEIDOS.

References

R. Saltus *et al.*, "Magnetic Maps and Models for Alternative Navigation," *2023 IEEE/ION Position, Location and Navigation Symposium (PLANS)*, Monterey, CA, USA, 2023, pp. 805-813, doi: 10.1109/PLANS53410.2023.10140025.

Saltus, R. W., et al. "Magnetic anomaly grid and associated uncertainty from marine trackline data: The Caribbean Alternative Navigation Reference Experiment (CANREx)." *Earth and Space Science* 10.11 (2023): e2023EA002958.

Acknowledgements

- Dr. Aaron Nielsen, Air Force Institute of Technology
- Dennis Brinkley, National Geospatial-Intelligence Agency
- Dr. Rick Blakely, U S Geological Survey (emeritus)
- **This research was supported by NOAA cooperative agreement NA22OAR4320151, CIESRDS (Cooperative Institute for Earth System Research and Data Science) and by a University grant from the Office of Naval Research.**