cesiumtoolkit: Unified Python Core and Legacy Framework for shipborne total-field magnetometer Processing

tags:

- Python, Fortran, Geophysics, Magnetometry, Data Integration, Data Visualization

authors:

- name: Hiroaki Koge

orcid: 0000-0002-8720-4975

corresponding: true

affiliation: 1

- name: Taichi Sato

orcid: 0000-0002-2158-3730

affiliation: 1

- name: Takemi Ishihara

orcid: 0000-0002-7852-2111

affiliation: 1

- name: Seshiro Furuyama

orcid: 0000-0002-5723-2027

affiliation: 1

- name: Seitaro Ono

orcid: 0009-0002-4555-7462

affiliation: 1

- name: Kyoko Okino

orcid:0000-0001-7070-7982

affiliation: 2

affiliations:

- name: "Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan"

index: 1

ror: 01703db54

- name: "Atmosphere and Ocean Research Institute, The University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa-shi, Chiba 277-8564, Japan"

index: 2

ror:057zh3y96

# Summary

‘cesiumtoolkit’ is a Python-centric package that consolidates every major stage of shipborne total-field magnetometer (TFM) processing into a single, scriptable workflow. The front-end driver ‘run-cesium.py’ converts raw sensor logs into intermediate ASCII files, applies moving-average smoothing, performs cable-layback correction to reconcile the spatial offset between the magnetometer and the vessel’s GPS antenna, executes International Geomagnetic Reference Field (IGRF) [@IAGA2024] subtraction via IAGA-VMOD/ppigrf [@Laundal2024], and prepares observatory records for diurnal-variation correction before applying the correction. After diurnal effects have been removed, the data are partitioned into straight-line survey legs and turning-motion intervals to facilitate line-based anomaly analysis. Crossover levelling is then performed by ‘run-crossover.py’, which wraps legacy Fortran routines in thin Python bindings to implement the Ishihara algorithm [@Ishihara2010]. The resulting outputs remain fully compatible with GMT’s ‘x2sys’ [@Wessel2010]; definition files and a Bash pipeline for batch processing reside in the ‘gmt/’ directory, alongside example scripts for gridding the final anomalies.

# Statement of Need

Traditional TFM processing relied on a scattered mix of Bash/Fortran/C/MATLAB scripts and executables, making execution order is opaque, reproducibility fragile, and modification cumbersome. ‘cesiumtoolkit’ replaces that sprawl with a single, readable codebase: top-level ’run-\*.py’ drivers lay out the entire sequence of steps, so users can follow the flow line-by-line and preserve intermediate outputs to guarantee reproducibility, while the numerical routines live in a modular API under ‘src/’, allowing algorithms to be swapped or extended without touching the rest of the pipeline. This arrangement lowers the entry barrier for newcomers and keeps the workflow transparent and maintainable.

## Documentation and Examples

A key feature of cesiumtoolkit is the first open-source packaging of the Ishihara crossover-adjustment algorithm [@Ishihara2015] for the Python ecosystem. Instead of re-implementing the routine from scratch, we wrap the original Fortran code in thin Python bindings, preserving its bit-level behaviour while making it directly callable from modern workflows. The method minimises line-to-line misfits not only at conventional crossover points but also in surveys where crossovers are sparse or unreliable. It explicitly models the combined effects of external-field disturbances, hull magnetisation, and navigation errors, iteratively solving for per-track level shifts that yield a self-consistent data set. This makes the algorithm especially valuable when observatory-based diurnal correction is impractical—e.g. in remote oceans far from fixed stations—or when CM4-based estimates of diurnal and secular variation carry large uncertainties [@Oda2021]. Its proven robustness led to adoption for integrating marine data into the second World Digital Magnetic Anomaly Map (WDMAM v2) [@Lesur2016].

### ‘./examples/GS24/’

This project demonstrates an end-to-end workflow for the GS24 cruise (G-880 cesium magnetometer. Geometrics Inc.). It includes raw ‘.txt’ logs, all intermediates produced by ‘run-cesium.py’ and ‘run-crossover.py’, and shell scripts for optional GMT gridding. Because licensing prevents redistribution of observatory data, users must download the one-minute Kakioka files [@Kakioka2013] themselves and place the ‘.min’ files in ‘examples/GS24/dv/’ before running the pipeline.

### ‘./examples/Hakuho/’

Provides a minimal sample of raw data recorded by a surface proton magnetometer (PR745, Kawasaki Geological Engineering Co., Ltd.) during the KH-22-10 cruise [@Koge2022], for use in quick file-conversion tests.

# Acknowledgements

We gratefully acknowledge the captains, crew, scientific parties, and participating students of the ‘Shinyo-maru’ (GS24 cruise) and ‘R/V Hakuho-maru’ (KH-22-10 cruise) for their invaluable support in magnetic data acquisition, instrument operation, and initial processing that made the development and validation of this toolkit possible.

Reference list (.bib format)

@article{Douglas1973,

author = {Douglas, David H. and Peucker, Thomas K.},

title = {Algorithms for the Reduction of the Number of Points Required to Represent a Digitized Line or Its Caricature},

journal = {Cartographica: The International Journal for Geographic Information and Geovisualization},

year = {1973},

volume = {10},

number = {2},

pages = {112--122},

doi = {10.1002/9780470669488.ch2},

}

@misc{IAGA2024,

author = {Ishihara, Takemi},

title = {IGRF-14 Version v2},

journal = {Zenodo},

year = {2024},

doi = {10.5281/zenodo.14218973},

url = {https://zenodo.org/records/14218973}

}

@article{Ishihara2015,

author = {Ishihara, Takemi},

title = {A New Leveling Method without the Direct Use of Crossover Data and Its Application in Marine Magnetic Surveys: Weighted Spatial Averaging and Temporal Filtering},

journal = {Earth, Planets and Space},

year = {2015},

volume = {67},

doi = {10.1186/s40623-015-0181-7},

}

@misc{KakiokaMagneticObservatory2013,

author = {{Kakioka Magnetic Observatory}},

title = {Kanoya geomagnetic field 1-minute digital data in IAGA-2002 format},

year = {2013},

howpublished = {Dataset, Kakioka Magnetic Observatory Digital Data Service},

doi = {10.48682/186fd.3f000},

}

@techreport{Koge2022,

author = {Hiroaki Koge},

title = {R/V HAKUHO MARU Cruise Report KH-22-10},

institution = {Japan Agency for Marine-Earth Science and Technology},

year = {2022},

type = {Cruise report},

doi = {10.17596/0003459}

}

@misc{Laundal2024,

author = {Laundal, Karl M. and Soler, Santiago and Smith, Ashley and Skeidsvoll, Andreas S. and Billett, Daniel and PB2

title = {IAGA-VMOD/ppigrf: 2.0.0},

journal = {Zenodo},

year = {2024},

doi = {10.5281/zenodo.14231854},

url = {https://zenodo.org/records/14231854}

}

@article{Lesur2016,

author = {Lesur, Vincent and Dyment, Jérôme and Hamoudi, Mohamed and Choi, Yunsoo and Thébault, Erwan and Catalán, Manuel and the WDMAM Task Force},

title = {The World Digital Magnetic Anomaly Map version 2},

journal = {Earth, Planets and Space},

volume = {68},

pages = {128},

year = {2016},

doi = {10.1186/s40623-016-0499-5}

}

@article{Oda2021,

author = {Oda, Hirokuni},

title = {World Digital Magnetic Anomaly Map and contribution from Japan},

journal = {GSJ Chishitsu News},

volume = {11},

number = {2},

pages = {31--41},

year = {2022},

url = {https://www.gsj.jp/data/gcn/gsj\_cn\_vol11.no2\_p31-41.pdf},

}

@article{Ramer1972,

author = {Ramer, Urs},

title = {An Iterative Procedure for the Polygonal Approximation of Plane Curves},

journal = {Computer Graphics and Image Processing},

year = {1972},

volume = {1},

number = {3},

pages = {244--256},

doi = {10.1016/S0146-664X(72)80017-0},

}

@article{Wessel2010,

author = {Wessel, Paul},

title = {Tools for Analyzing Intersecting Tracks: the x2sys Package},

journal = {Computers & Geosciences},

year = {2010},

volume = {36},

pages = {348--354},

doi = {10.1016/j.cageo.2009.05.009},

}

@article{Wessel2019,

author = {Wessel, Paul and Luis, José F. and Uieda, Leonardo A. and Scharroo, Remko and Wobbe, Florian and Smith, W. H. F. and Tian, Dawei},

title = {The Generic Mapping Tools Version 6},

journal = {Geochemistry, Geophysics, Geosystems},

year = {2019},

volume = {20},

number = {11},

pages = {5556--5564},

doi = {10.1029/2019GC008515},

}