

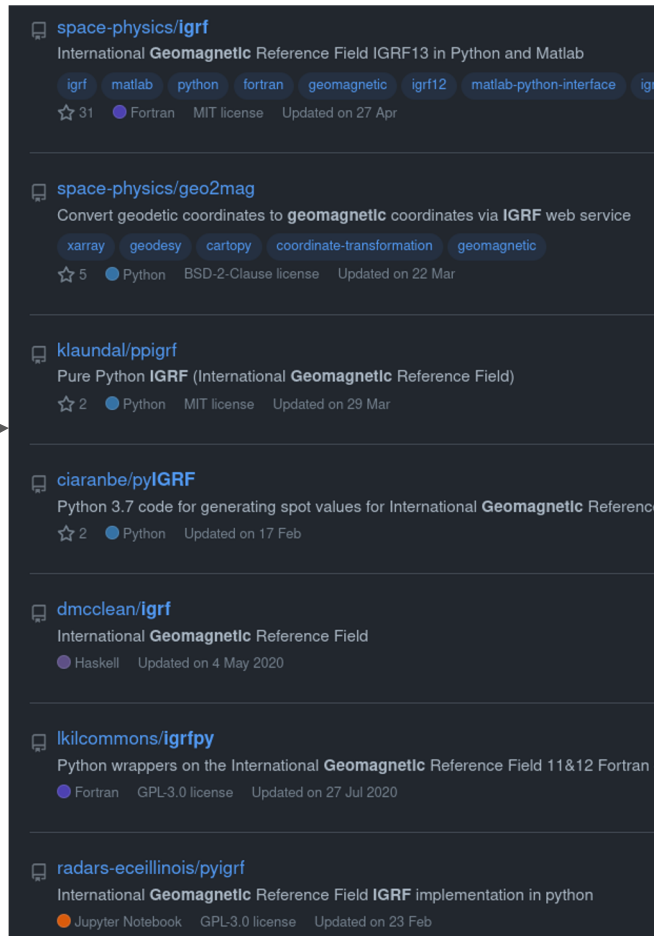
IGRF in Python

Community consensus & tools
for near-Earth geomagnetic field models

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Outline

- IGRF is used for many different purposes
- Need a simple reference Python implementation of IGRF, agreed by community
- Could coordinate efforts better
- More generally:
A pattern to follow for other models?
e.g. IRI, MSIS-E, ...
(considering sustainability, wide user base, ...)



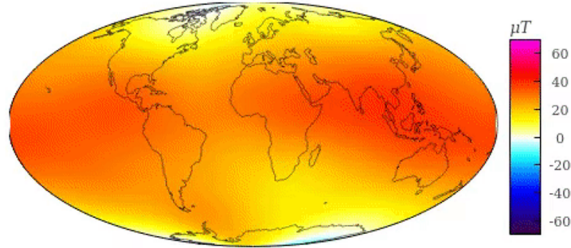
What is IGRF?

International Geomagnetic Reference Field 13

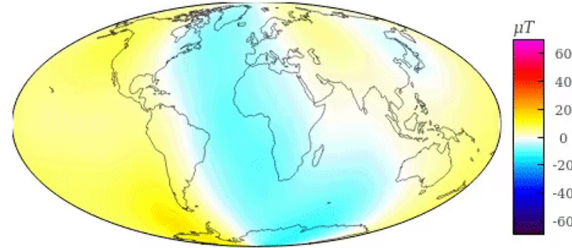
defined over 1900-

1900-01-01 (IGRF-13)

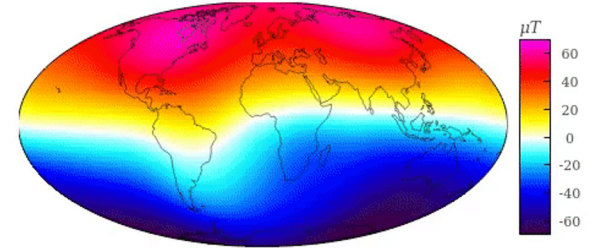
Northward (X)



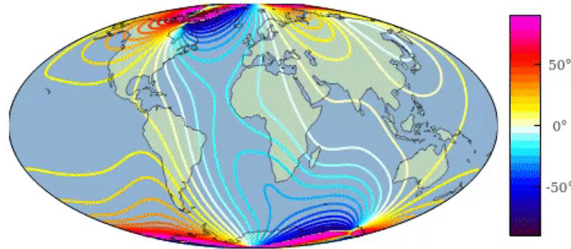
Eastward (Y)



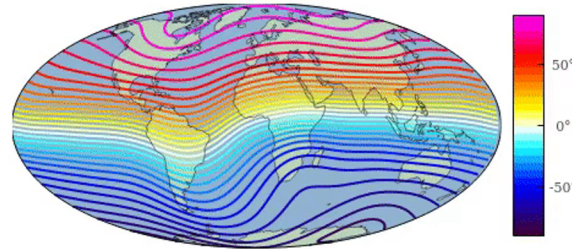
Downward (Z)



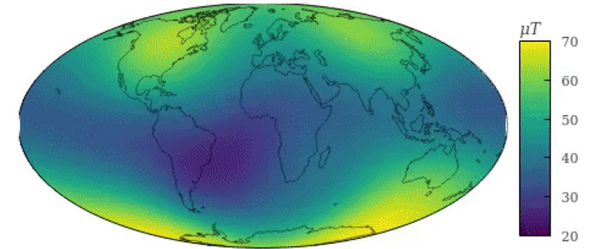
Declination (D)



Inclination (I)



Intensity (F)



What is IGRF?

$$\vec{B} = -\nabla V$$

$$V = R_E \sum_{l=1}^N \sum_{m=0}^l (g_l^m \cos m\phi + h_l^m \sin m\phi) \left(\frac{R_E}{r}\right)^{l+1} P_l^m(\cos \theta)$$

Spherical harmonic description up to degree $l=13$ (195 Gauss coefficients)

Snapshot every 5 years with linear interpolation between

```
# 13th Generation International Geomagnetic Reference Field Schmidt semi-normalised spher
# in units nanoTesla for IGRF and definitive DGRF main-field models (degree n=1,8 nanoT
c/s deg ord IGRF IGRF IGRF IGRF IGRF IGRF IGRF IGRF IGRF IGRF DGRF DGRF
g/h n m 1900.0 1905.0 1910.0 1915.0 1920.0 1925.0 1930.0 1935.0 1940.0 1945.0 1950.0 195
g 1 0 -31543 -31464 -31354 -31212 -31060 -30926 -30805 -30715 -30654 -30594 -30554 -30
g 1 1 -2298 -2298 -2297 -2306 -2317 -2318 -2316 -2306 -2292 -2285 -2250 -2
h 1 1 5922 5909 5898 5875 5845 5817 5808 5812 5821 5810 5815 5
g 2 0 -677 -728 -769 -802 -839 -893 -951 -1018 -1106 -1244 -1341 -1
g 2 1 2905 2928 2948 2956 2959 2969 2980 2984 2981 2990 2998 3
h 2 1 -1061 -1086 -1128 -1191 -1259 -1334 -1424 -1520 -1614 -1702 -1810 -1
g 2 2 924 1041 1176 1309 1407 1471 1517 1550 1566 1578 1576 1
h 2 2 1121 1065 1000 917 823 728 644 586 528 477 381
g 3 0 1022 1037 1058 1084 1111 1140 1172 1206 1240 1282 1297 1
g 3 1 -1469 -1494 -1524 -1559 -1600 -1645 -1692 -1740 -1790 -1834 -1889 -1
```

What is IGRF?

- Construction of IGRF is a 5-yearly activity organised by IAGA
- Many more complex candidate models are merged (weighted average of Gauss coefficients): this is published as the IGRF

<https://www.ngdc.noaa.gov/IAGA/vmod/index.html>

[International Geomagnetic Reference Field: the thirteenth generation, Alken et al. 2021](#)

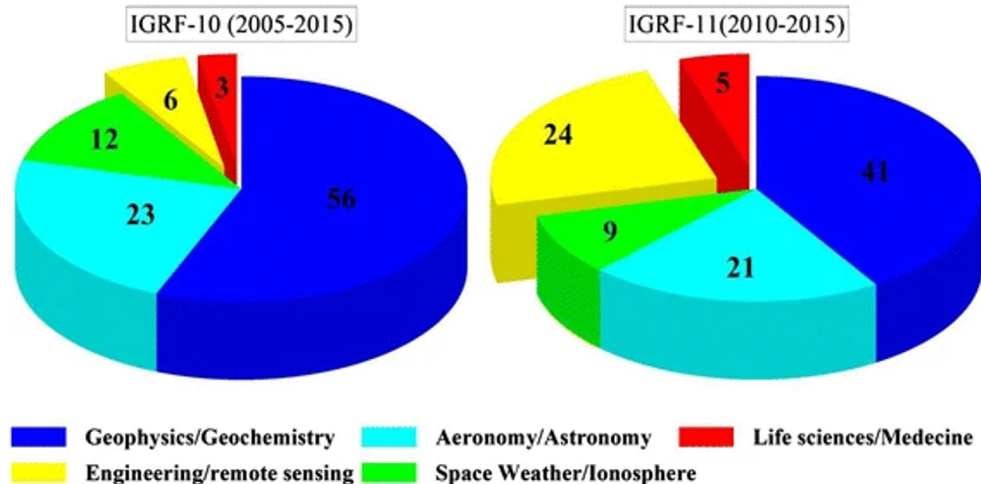
```
# 13th Generation International Geomagnetic Reference Field Schmidt semi-normalised sphere
# in units nanoTesla for IGRF and definitive DGRF main-field models (degree n=1,8 nanoTesla)
c/s deg ord IGRF IGRF IGRF IGRF IGRF IGRF IGRF IGRF IGRF IGRF DGRF DGRF
g/h n m 1900.0 1905.0 1910.0 1915.0 1920.0 1925.0 1930.0 1935.0 1940.0 1945.0 1950.0 1955.0
g 1 0 -31543 -31464 -31354 -31212 -31060 -30926 -30805 -30715 -30654 -30594 -30554 -30514
g 1 1 -2298 -2298 -2297 -2306 -2317 -2318 -2316 -2306 -2292 -2285 -2250 -2240
h 1 1 5922 5909 5898 5875 5845 5817 5808 5812 5821 5810 5815 5810
g 2 0 -677 -728 -769 -802 -839 -893 -951 -1018 -1106 -1244 -1341 -1441
g 2 1 2905 2928 2948 2956 2959 2969 2980 2984 2981 2990 2998 3006 3014
h 2 1 -1061 -1086 -1128 -1191 -1259 -1334 -1424 -1520 -1614 -1702 -1810 -1910 -2010
g 2 2 924 1041 1176 1309 1407 1471 1517 1550 1566 1578 1576 1576 1576
h 2 2 1121 1065 1000 917 823 728 644 586 528 477 381 311 241
g 3 0 1022 1037 1058 1084 1111 1140 1172 1206 1240 1282 1297 1306 1315
g 3 1 -1469 -1494 -1524 -1559 -1600 -1645 -1692 -1740 -1790 -1834 -1889 -1934 -1984
```

Beyond IGRF

- When is IGRF not enough?
e.g. probing ionospheric magnetic signals at LEO -> better to use more accurate internal field and magnetospheric model like CHAOS
See magneticearth.org/pages/models.html
- Need a smoother pathway for people to understand when to move beyond IGRF, and how to do that

Wide & Varied User Base

- Data analysis/interpretation
- Numerical modelers
- Operational users - NASA, NOAA, DoD, Commercial Entities
- Students



Uses in space physics

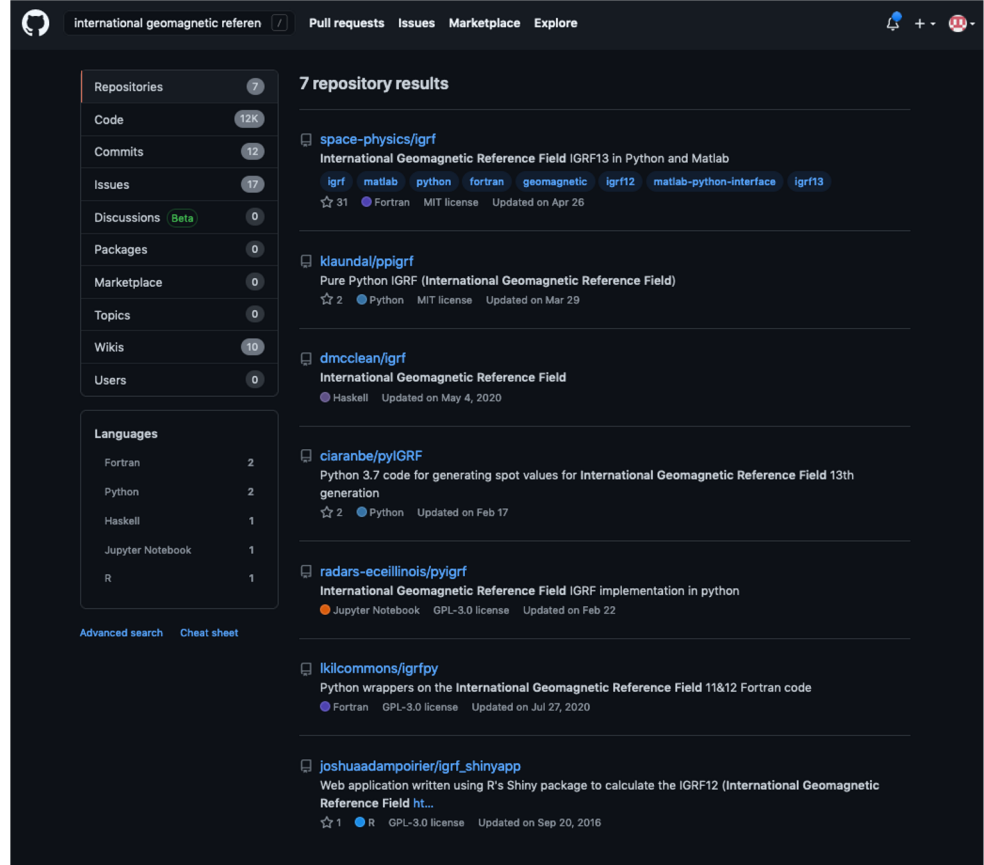
- Model evaluation (what is the main field at $x,y,z?$)
- Field line tracing
- Coordinate systems (e.g. AACGM, QD ...)
- Coupling to Tsyganenko models
- Interpreting magnetometer data
- Input into first-principal/empirical models
- ...

Uses in geophysics

- Model evaluation (what is the main field at $x,y,z?$)
- Geomagnetic field modelling (power spectra, model comparison...)
- Correction processes in crustal and MT surveys
- ...

Many Existing Implementations

- IAGA traditionally publish an old Fortran code updated with the latest coefficients
- Many other implementations and web services exist
- IGRF coefficients are also used in other tools (e.g. AACGM, GEOPACK)
- Currently not an obvious choice which Python package to use
 - “International Geomagnetic Reference Field” - 7 repos
 - “IGRF” - 45 repos



The screenshot shows a GitHub search results page for the query "international geomagnetic referen". The page displays 7 repository results. The left sidebar shows filters for Repositories (7), Code (12K), Commits (12), Issues (17), Discussions (Beta, 0), Packages (0), Marketplace (0), Topics (0), Wikis (10), and Users (0). Below the sidebar, there is a table for Languages: Fortran (2), Python (2), Haskell (1), Jupyter Notebook (1), and R (1). The main content area lists the following repositories:

- space-physics/igrf**: International Geomagnetic Reference Field IGRF13 in Python and Matlab. Languages: igrf, matlab, python, fortran, geomagnetic, igrf12, matlab-python-interface, igrf13. 31 stars, Fortran, MIT license, updated on Apr 26.
- klaundal/ppigrf**: Pure Python IGRF (International Geomagnetic Reference Field). 2 stars, Python, MIT license, updated on Mar 29.
- dmccllean/igrf**: International Geomagnetic Reference Field. Haskell, updated on May 4, 2020.
- ciarambe/pyIGRF**: Python 3.7 code for generating spot values for International Geomagnetic Reference Field 13th generation. 2 stars, Python, updated on Feb 17.
- radars-eceillinois/pyigrf**: International Geomagnetic Reference Field IGRF implementation in python. Jupyter Notebook, GPL-3.0 license, updated on Feb 22.
- lkilcommons/igrfpy**: Python wrappers on the International Geomagnetic Reference Field 11&12 Fortran code. Fortran, GPL-3.0 license, updated on Jul 27, 2020.
- joshuaadampoirier/igrf_shinyapp**: Web application written using R's Shiny package to calculate the IGRF12 (International Geomagnetic Reference Field ht...). 1 star, R, GPL-3.0 license, updated on Sep 20, 2016.

Tabulation of various packages: <https://github.com/ciarambe/pyIGRF/issues/2>

Potential Requirements

- **Ease of use**
 - Simple pip install that works on all platforms immediately
 - Simple interface
- **Performance**
 - A pure Python implementation (using available tools in numpy/scipy) is slower
 - [eoxmagmod](#) from Swarm mission (C++ underneath) is fastest - WIP to fix distribution & documentation (provides several models beyond IGRF)
- **Features**
 - Flexible forwards evaluation
 - Field line tracing (see e.g. [rstoneback/OMMBV](#))
 - Geomagnetic field modelling toolbox (much already available in [ChaosMagPy](#))
 - Select which version (year) of the model to use
- **Maintainability**
 - Clean code base
 - Well documented, both for users and developers
 - Avoid “scope creep” (adding many specialized features such that the package becomes large and/or fragile)
 - A guiding/parent organization to support development

Discussion Questions

- Is having many “python IGRFs” a problem?
- Can we as a community coordinate our efforts better?
- Who should be in charge of the “standard” python IGRF library?
- What features should the “standard” library have?
- How should this effort be organized/funded?
- How can this apply to other similar tools (IRI, MSIS, ect)?

Discussion Notes

- NGDC python package
- CCMC provides access
- Nice if IAGA is involved - not strictly required
- CCMC web interface - nice resource for the community, but many people want to be able run the model locally
- Coordinate - solar community has gathered around sunpy, astropy, ect?
 - Do we want to try to take this approach? Organize the community around a single packages
- Centralized package - dependencies issues
 - Can be problem for maintenance
 - Maybe all these large models can be collected at least
- NASA ML call - produce something ML ready (machine learning)
 - Maybe helpful to have a funding opportunity like this
 - HDEE - possible funding opportunity - 1-2 years
 - White paper for decadal survey
 - Opportunity for our community to demonstrate the advantages of open source
- Pysat - lets community be decentralized, but pysat connects everything - Metapackage?
 - Let things easily talk to each other
- Software publication is important!!!
 - Publishing jupyter notebooks
 - JOSS