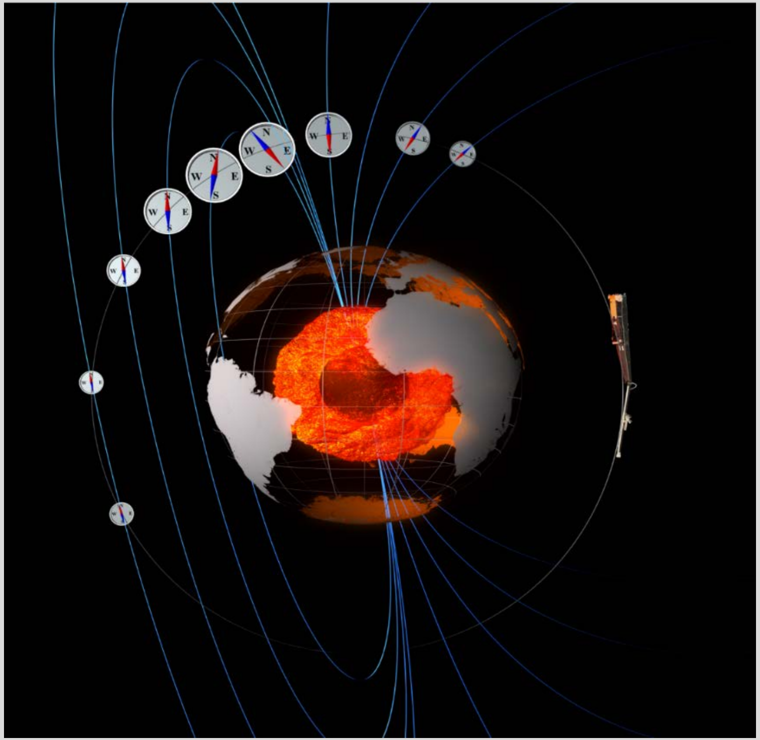
International Geomagnetic Reference Field (IGRF)



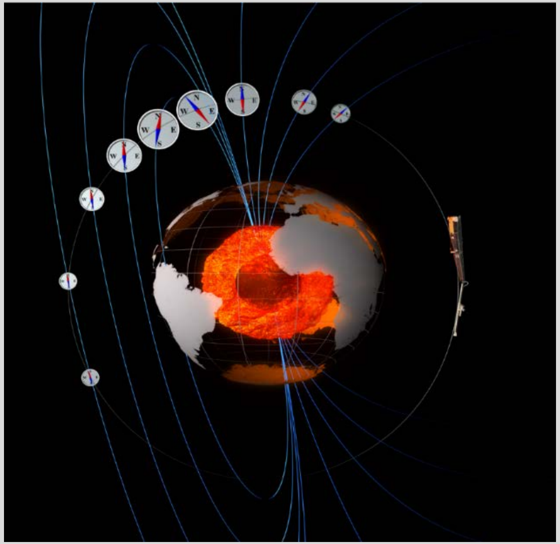
- Sources of the geomagnetic field
    - Main, crustal and disturbance field
- Measurements used to produce IGRF
- How the IGRF is parameterized
- Errors of omission and commission
- IGRF reference materials
    - Documentation
    - Software

Swarm Mission
European Space Agency

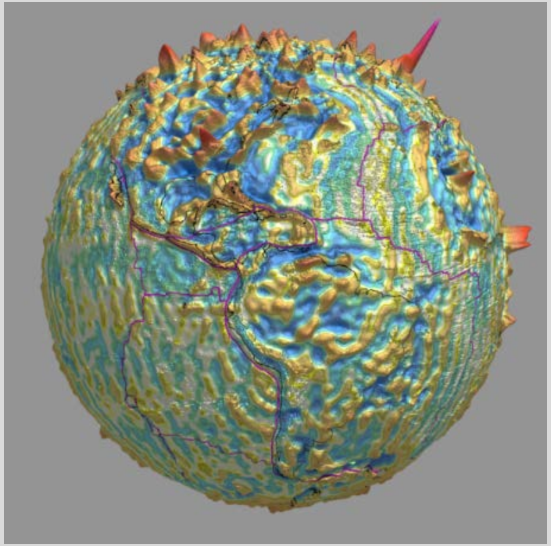
Stefan Maus (CIRES, University of Colorado Boulder)

The Three Sources of the Geomagnetic Field

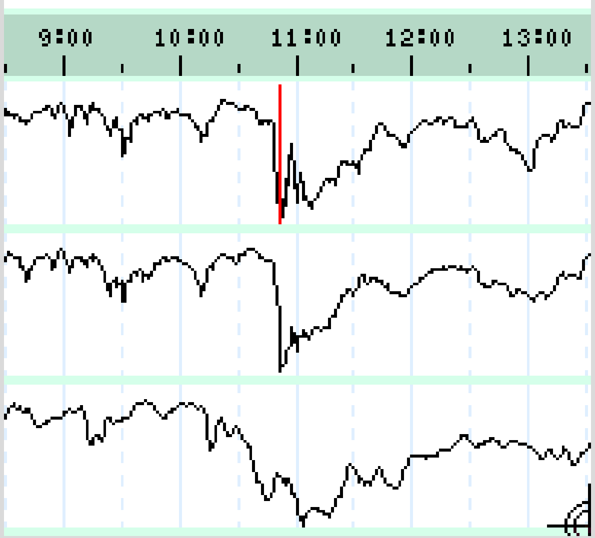
Main field



Crustal field

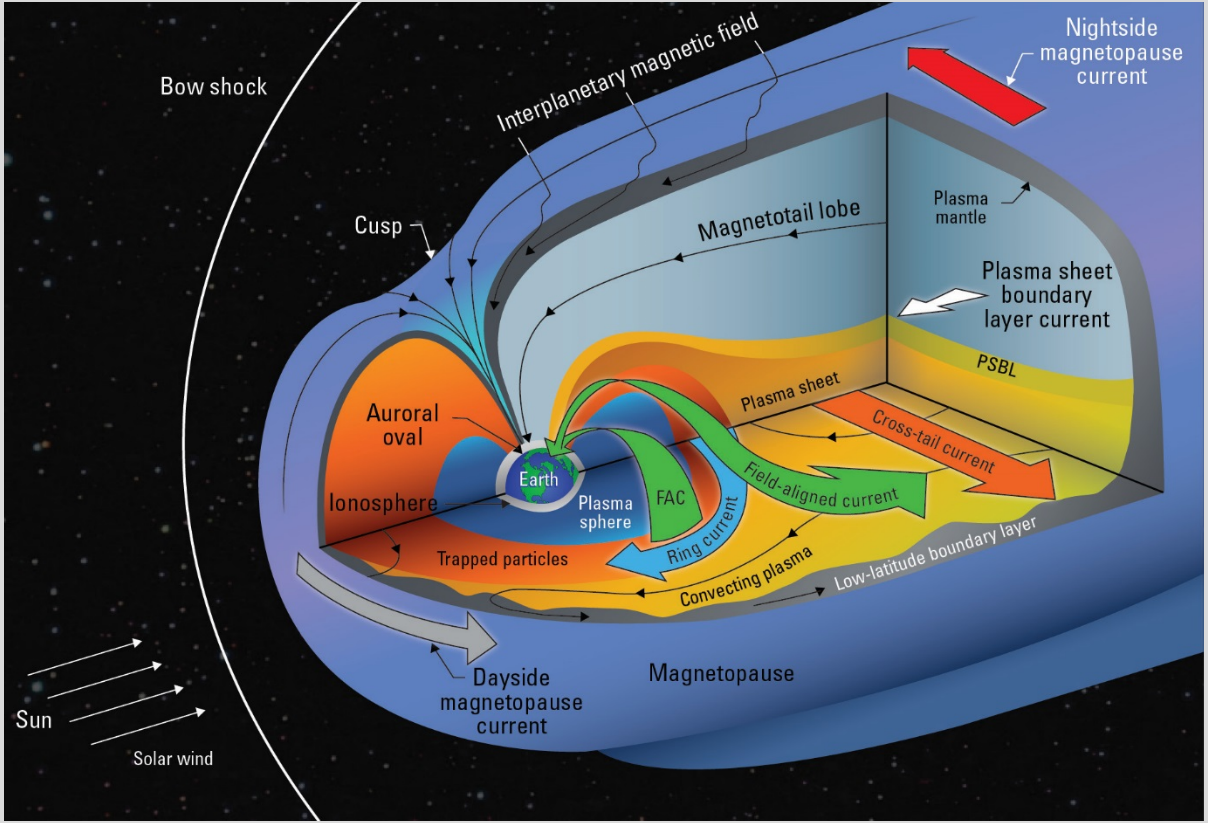


Disturbance field



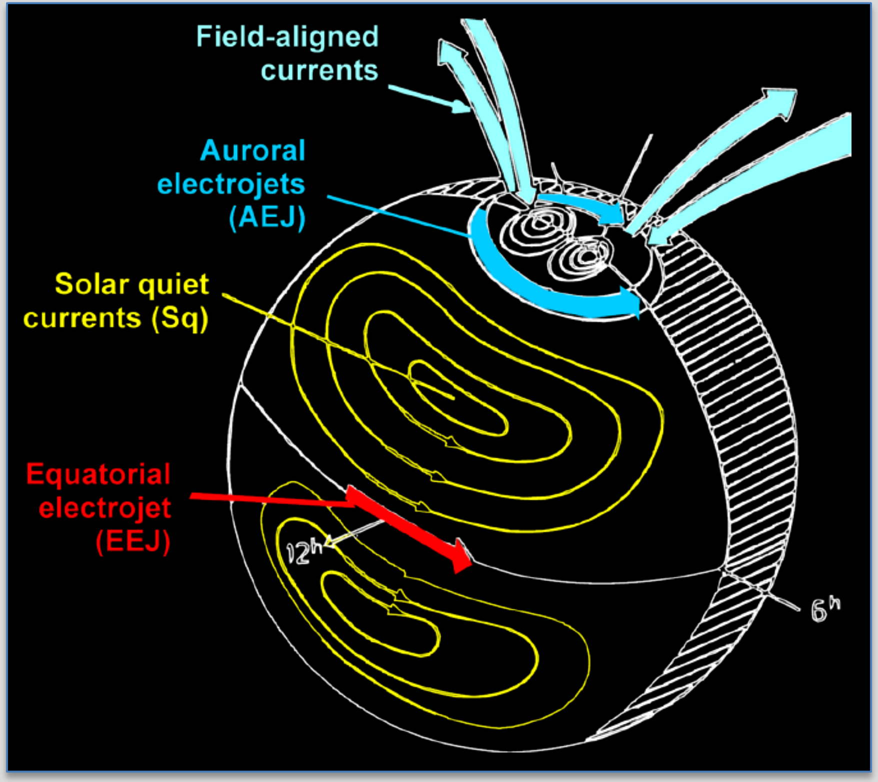
Sources of Magnetospheric Magnetic Fields

- Ring current
- Cross-tail current
- Magnetopause currents
- Field-aligned currents



From OTC-24583-MS

Sources of Ionospheric Magnetic Fields



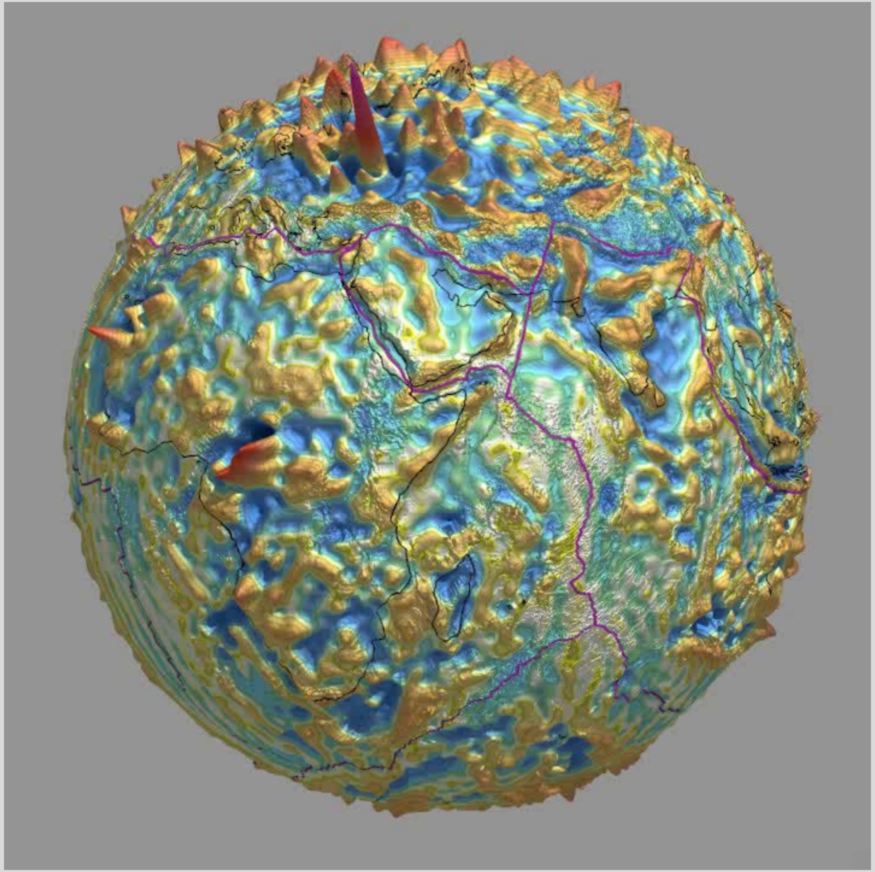
- Field Aligned currents
- Polar electrojets
- Sq currents
- Equatorial electrojet

Induced Fields:

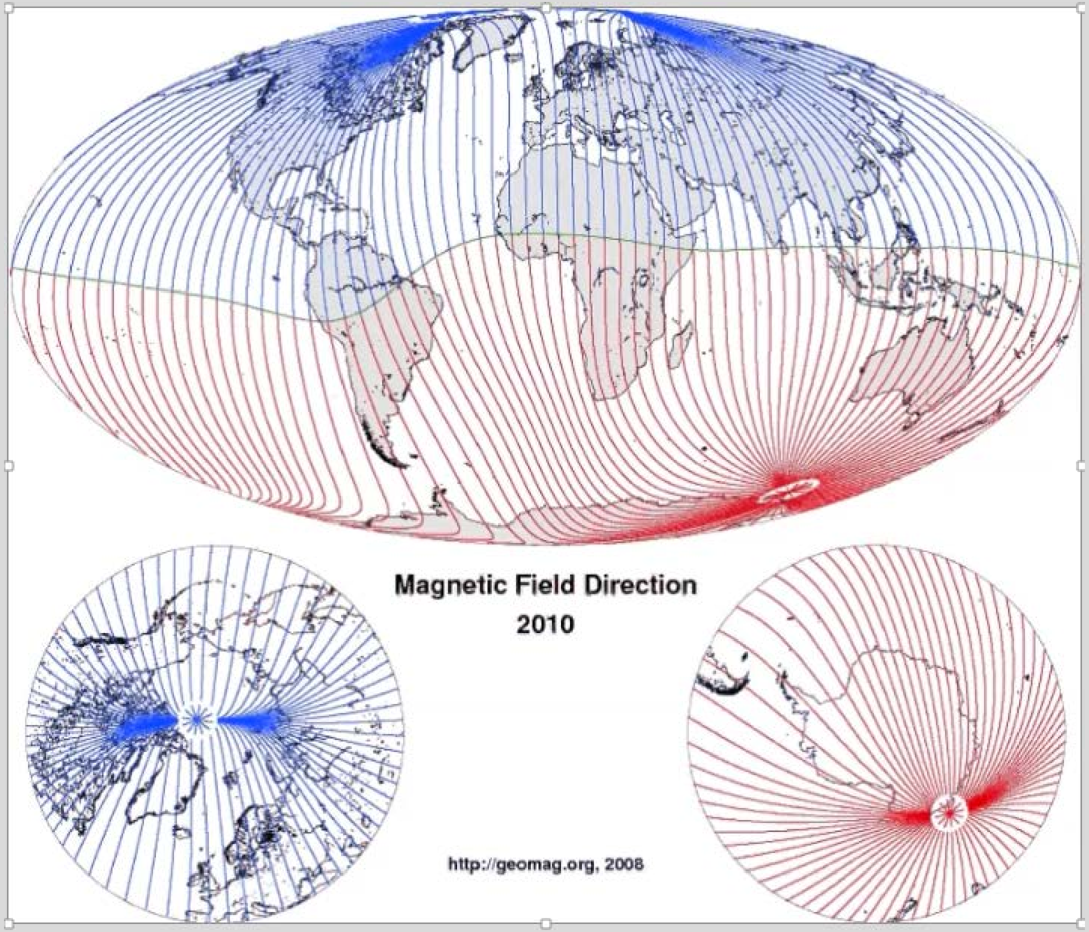
The magnetospheric and ionospheric fields further induce electric currents in the Earth, which give rise to secondary "induced" magnetic fields.

Crustal Magnetic Field as Seen by CHAMP Satellite

Vertical component of the magnetic field downward continued to 50 km altitude



MF7 Model Animation by Rother and Maus



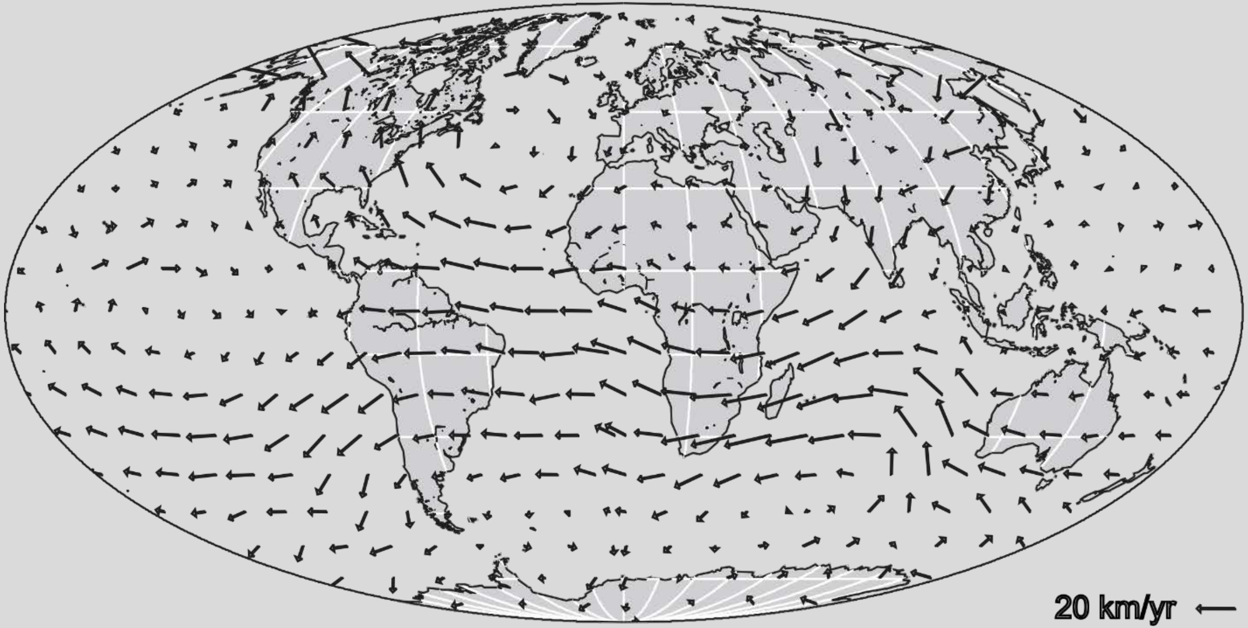
Main Field

Magnetic field lines and magnetic equator

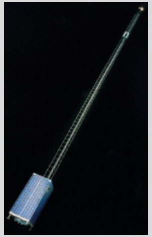
1590 - 2010

Core Flow and Westward Drift

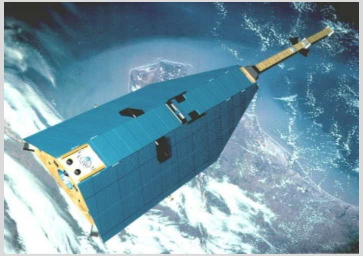
Assuming that magnetic flux is “frozen-into” the core fluid, one can invert the secular variation of the geomagnetic field to find corresponding flows at the top of the outer core



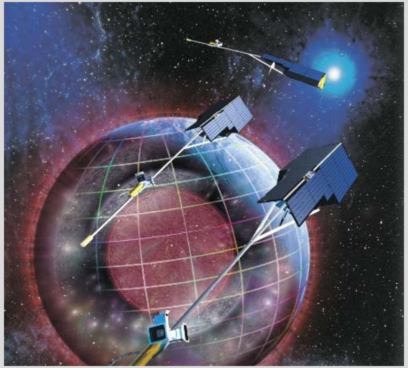
Magnetic Field Measurements



Ørsted (1999-2014)

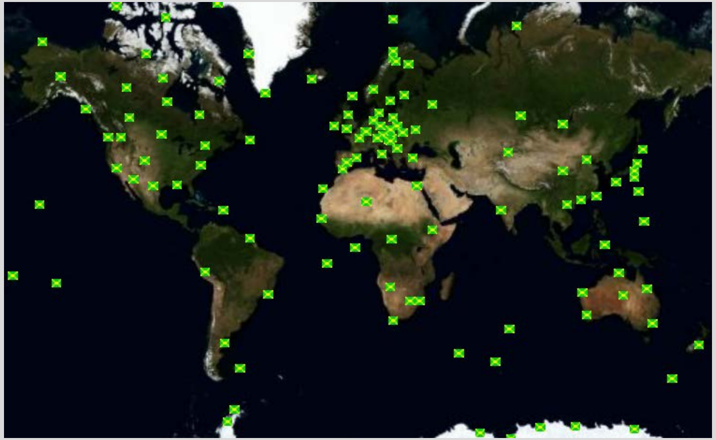


CHAMP
2000-2010



Swarm
since 2013

Geomagnetic observatories



ACE/DSCVR used for data selection at high latitudes

Parameterization of the IGRF

Write the magnetic field vector as gradient of a potential *V*: $\mathbf{B} = -\nabla V$

Spherical harmonic expansion of potential *V*:

$$V(\lambda,\psi,r,t) = a\sum_{n=1}^{N}\sum_{m=0}^{n}\left(\frac{a}{r}\right)^{n+1}\left(g_n^m(t)\cos m\lambda + h_n^m(t)\sin m\lambda\right)\mathrm{P}_n^m(\sin\psi)$$

N = Degree of the model

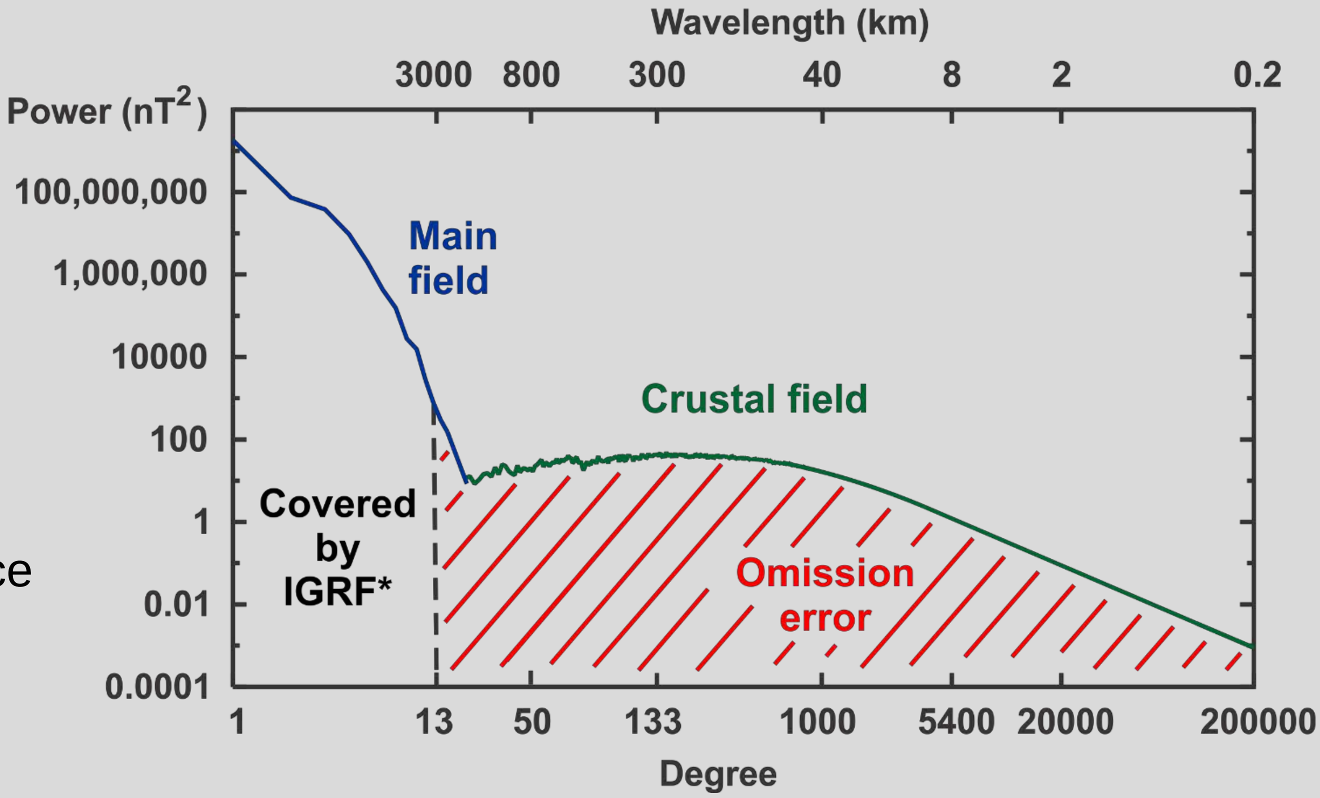
a = Geomagnetic reference radius (6371.2 km)

$g_n^m(t) = g_n^m(t_0) + \dot{g}_n^m$ and $h_n^m(t) = h_n^m(t_0) + \dot{h}_n^m$: Model coefficients

$\mathrm{P}_n^m(\sin\psi)$: Associated Legendre functions

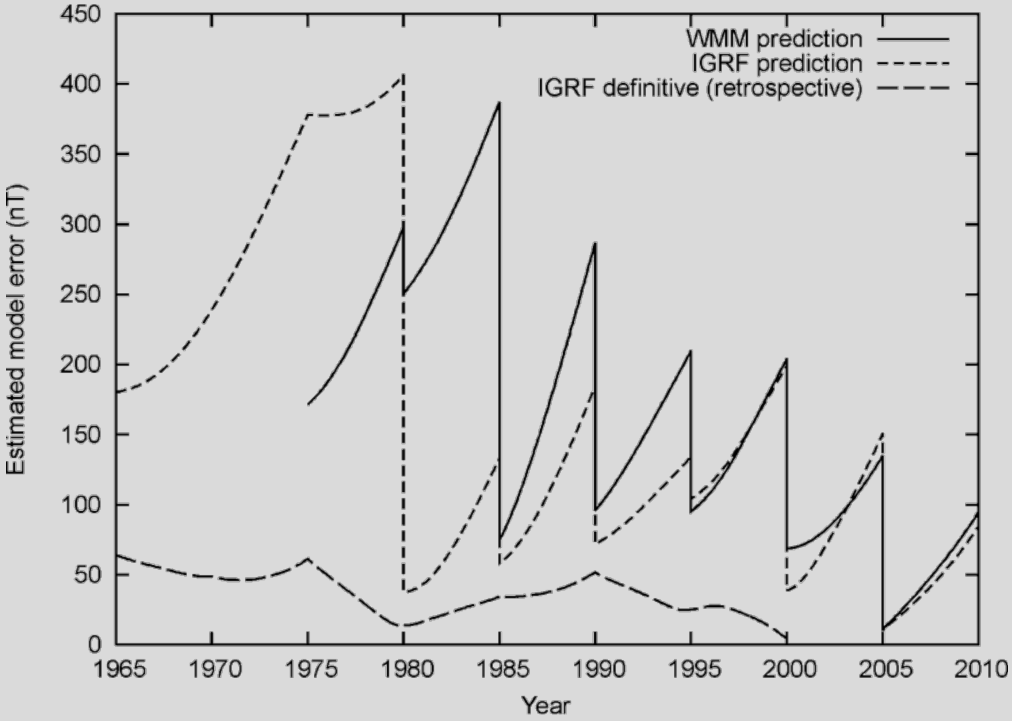
IGRF Error of Omission

Geomagnetic power spectrum at Earth surface



*IGRF = International Geomagnetic Reference Field

IGRF error of commission



Errors of the IGRF coefficients themselves are called **commission error.**

The IGRF predictive error (dashed) increases for 5 years until the IGRF is next updated.

The IGRF is much more accurate when evaluated for dates in the past, which are covered by actual measurements.

IGRF Background

- Updated every 5 years, extends back to 1900
- Managed by IAGA - Division 5 – Working Group V-MOD
- Chair and Co-Chair change every 4 years
- Current Chair: Erwan Thébault, Co-Chair: Patrick Alken
- Current 12th Generation IGRF citation:

Erwan Thébault, Christopher C Finlay, Ciarán D Beggan, Patrick Alken, Julien Aubert, Olivier Barrois, Francois Bertrand, Tatiana Bondar, Axel Boness, Laura Brocco, Elisabeth Canet, Aude Chambodut, Arnaud Chulliat, Pierdavide Coïsson, Francois Civet, Aimin Du, Alexandre Fournier, Isabelle Fratter, Nicolas Gillet, Brian Hamilton, Mohamed Hamoudi, Gauthier Hulot, Thomas Jager, Monika Korte, Weijia Kuang, Xavier Lalanne, Benoit Langlais, Jean-Michel Léger, Vincent Lesur, Frank J Lowes et al. Earth, Planets and Space 2015, 67:79 (27 May 2015)

IGRF Home Page

http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html

- Stand-alone software: Fortran and C
- Health Warning on the limitations of the IGRF
- Citation of the current model publication
- Older versions (“generations”) of the IGRF

IGRF Online Calculators

- http://www.ngdc.noaa.gov/geomag-web/?model=igrf
- http://omniweb.gsfc.nasa.gov/vitmo/cgm_vitmo.html
- http://geomag.org/models/igrfplus-field.html

Magnetic Field

Model Used:	IGRF12
Latitude:	35° 40' 59" N
Longitude:	105° 56' 31" W
Elevation:	0.0 km Mean Sea Level

Date	Declination (+ E | - W)	Inclination (+ D | - U)	Horizontal Intensity	North Comp (+ N | - S)	East Comp (+ E | - W)	Vertical Comp (+ D | - U)	Total Field
2016-06-22	8° 27' 10"	62° 45' 55"	22,799.1 nT	22,551.5 nT	3,351.3 nT	44,296.1 nT	49,819.1 nT
Change/year	-0° 6' 11"/yr	-0° 0' 50"/yr	-38.2 nT/yr	-31.8 nT/yr	-46.2 nT/yr	-100.6 nT/yr	-106.9 nT/yr

CGM and Apex Coordinates

- http://omniweb.gsfc.nasa.gov/vitmo/cgm_vitmo.html
- http://www.ngdc.noaa.gov/geomag/geom_util/apex.shtml

Magnetic apex coordinate subroutine library (Emmert & Richmond):

- https://apexpy.readthedocs.org/

Emmert, J. T., A. D. Richmond, and D. P. Drob (2010), A computationally compact representation of Magnetic-Apex and Quasi-Dipole coordinates with smooth base vectors, J. Geophys. Res., 115(A8), A08322, doi:10.1029/2010JA015326.

Richmond, A. D. (1995), Ionospheric Electrodynamics Using Magnetic Apex Coordinates, Journal of geomagnetism and geoelectricity, 47(2), 191–212, doi:10.5636/jgg.47.191

ISO Standard 16695

ISO-16695: Space environment (natural and artificial) — Geomagnetic reference models

- Detailed description of the IGRF model
- Actual ISO standard document available for purchase at http://www.iso.org/iso/catalogue_detail.htm?csnumber=57448
- Draft version is available at: http://www.spacewx.com/Docs/ISO16695_Magfield_7.0_review.pdf

Summary

- The geomagnetic field can be divided into three contributions, (1) main field, (2) crustal field and (3) disturbance field
- The IGRF only represents the main field, originating in the core
- IGRF includes linear change - also called secular variation
- Updated every 5 years to account for non-linear changes
- IGRF Home Page: http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html
- ISO Standard: http://www.spacewx.com/Docs/ISO16695_Magfield_7.0_review.pdf
- Magnetic apex coordinates: https://apexpy.readthedocs.org/