IAGA V-MOD BUSINESS MEETING

August 23, 2021

Proposed Agenda

- Acceptance of proposed agenda
- Report on IGRF-13
- Status of data available for field modeling
- Spatial uncertainty of IGRF models
- Possible revisit of DGRF-2010
- Report on WDMAM
- 2023 IAGA sessions
- Any other business

1. Report on IGRF-13

IGRF-13 timeline

Mar 26 2019: IGRF-13 call released

Oct 1 2019: deadline for candidate model submissions

Oct-Dec 2019: task force evaluates candidates

Dec 2019: task force vote and construction of final model

Jan 1 2020: IGRF-13 released

Review of IGRF-13 candidate models

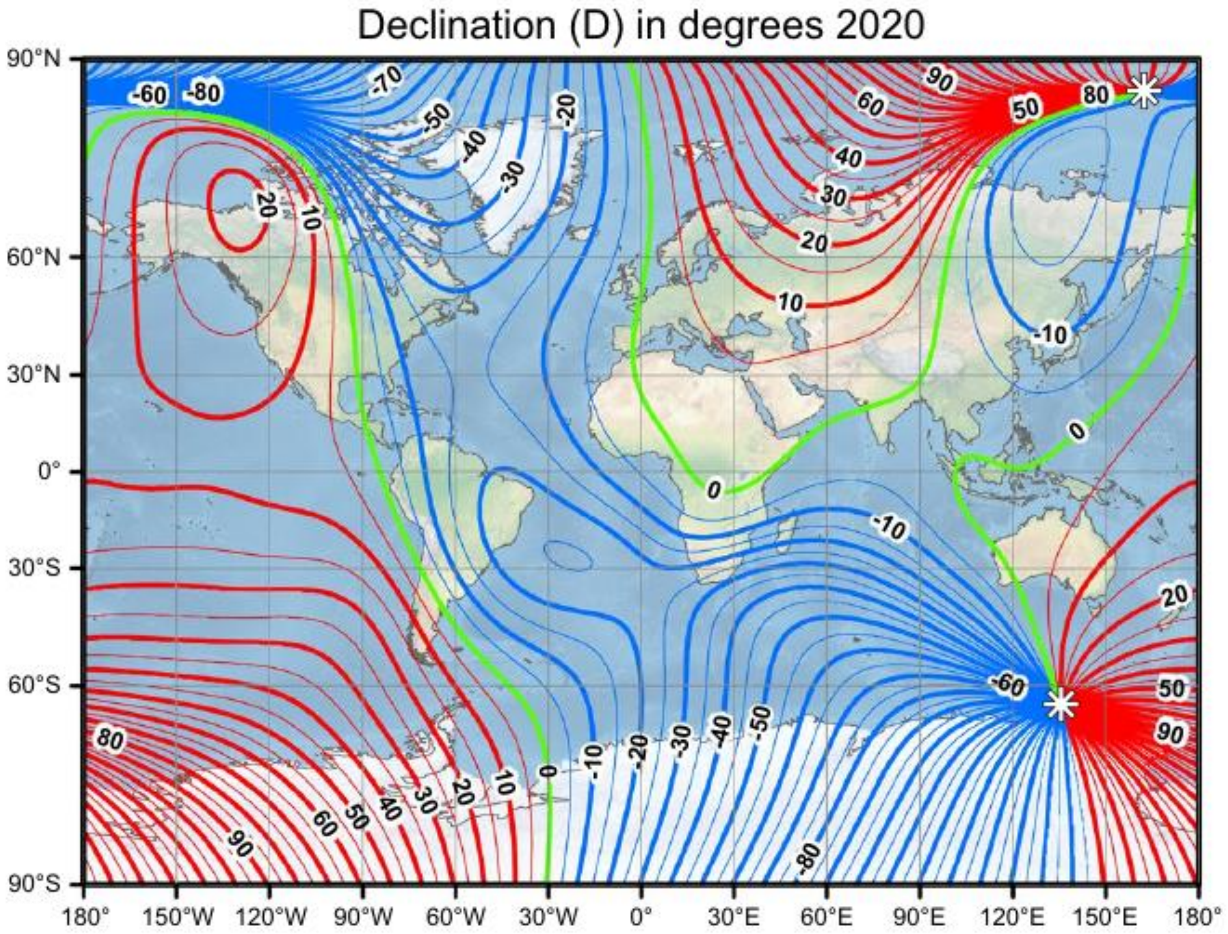
Table 1 Teams who submitted IGRF-13 candidate models

Letter Code	Lead Institute	DGRF2015	IGRF2020	SV2020-2025	References
B	British Geological Survey	✓	✓	✓	Brown et al. (2020)
CE	China Earthquake Administration		✓		Yang et al. (2020)
CM	Universidad Complutense de Madrid	✓	✓	✓	Pavón-Carrasco et al. (2020)
CU	University of Colorado Boulder	✓	✓	✓	Alken et al. (2020a)
D	Technical University of Denmark (DTU Space)	✓	✓	✓	Finlay et al. (2020)
G	GFZ German Research Centre for Geosciences	✓	✓	✓	Rother et al. (2020)
IP	Institut de physique du globe de Paris	✓	✓	✓	Fournier et al. (2020); Ropp et al. (2020); Vigneron et al. (2020)
IS	Institut des Sciences de la Terre	✓	✓	✓	Huder et al. (2020)
IZ	Pushkov Institute of Terrestrial Magnetism (IZMIRAN)	✓	✓	✓	Petrov and Bondar (2020)
K	Kyoto University			✓	Minami et al. (2020)
L	University of Leeds			✓	Metman et al. (2020)
M	Max Planck Institute for Solar System Research			✓	Sanchez et al. (2020)
N	NASA Goddard Space Flight Center	✓	✓	✓	Sabaka et al. (2020); Tangborn et al. (2020)
P	University of Potsdam	✓	✓	✓	Baerenzung et al. (2020)
S	Université de Strasbourg	✓	✓	✓	Wardinski et al. (2020)

15 international teams submitted candidate models for IGRF-13

Overview of final IGRF-13 model

- Validity period: 1900 to 2025
- Secular variation forecast from 2020 to 2025
- Large-scale field of internal origin to SH degree/order 13
- DGRF-2015 and IGRF-2020 coefficients were taken as the median of all candidate models
- SV2020-2025 coefficients were computed using a robust Huber weighting in space
- Model detailed in *Alken et al, Earth Planets Space, 73:48, 2021* and *Alken et al, Earth Planets Space, 73:49, 2021*



Pole movements

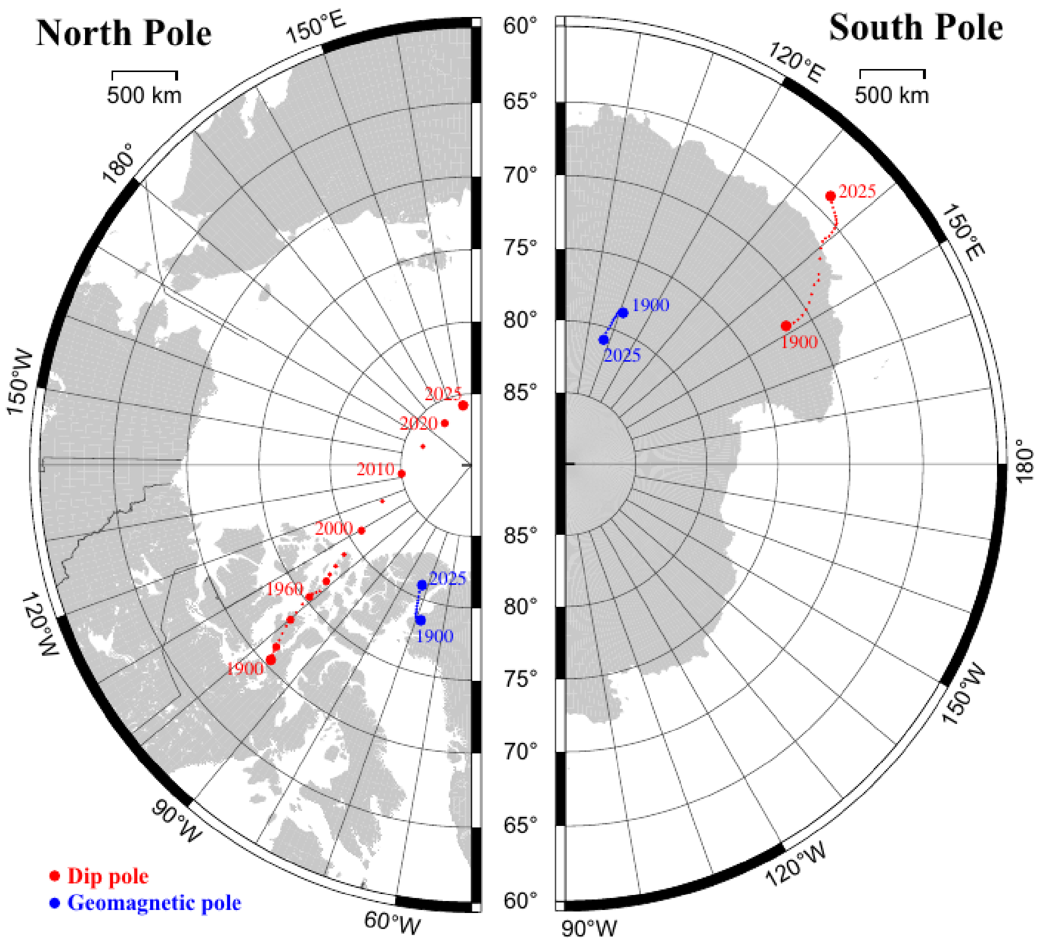


Fig. 3 Motion of the magnetic dip pole (red) and geomagnetic pole (blue) since 1900 from IGRF-13 in the northern hemisphere (left) and southern hemisphere (right). The scale provides an indication of distance on the WGS84 ellipsoid that is correct along lines of constant longitude and also along the middle lines of latitude shown. Note the left and right panels use different longitude ranges. The maps use stereographic projection. International and provincial boundaries are drawn in the left panel

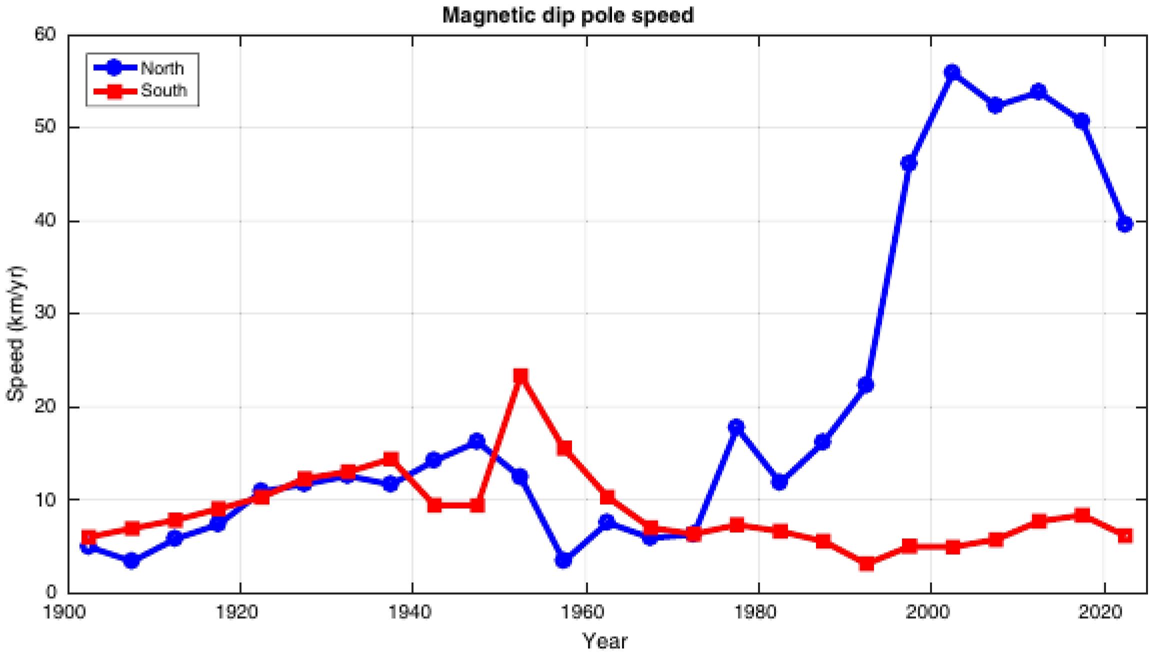


Fig. 4 Average speed of the magnetic dip poles over each 5-year epoch, plotted at the midpoint between epochs (i.e., the speed over 2015–2020 is shown at 2017.5). The value for 2020–2025 is a forecast

Alken et al, EPS, 73:49, 2021

Analysis of IGRF-12 forecast (1/4)

- IGRF-12, released in 2015, provided a secular variation forecast for 2015-2020
- The task force compared these candidates with the final IGRF-13 model and also observatory data to determine which candidates performed best
- Results are detailed in Alken et al, *Earth Planets Space*, 73:48, 2021

Analysis of IGRF-12 forecast (2/4)

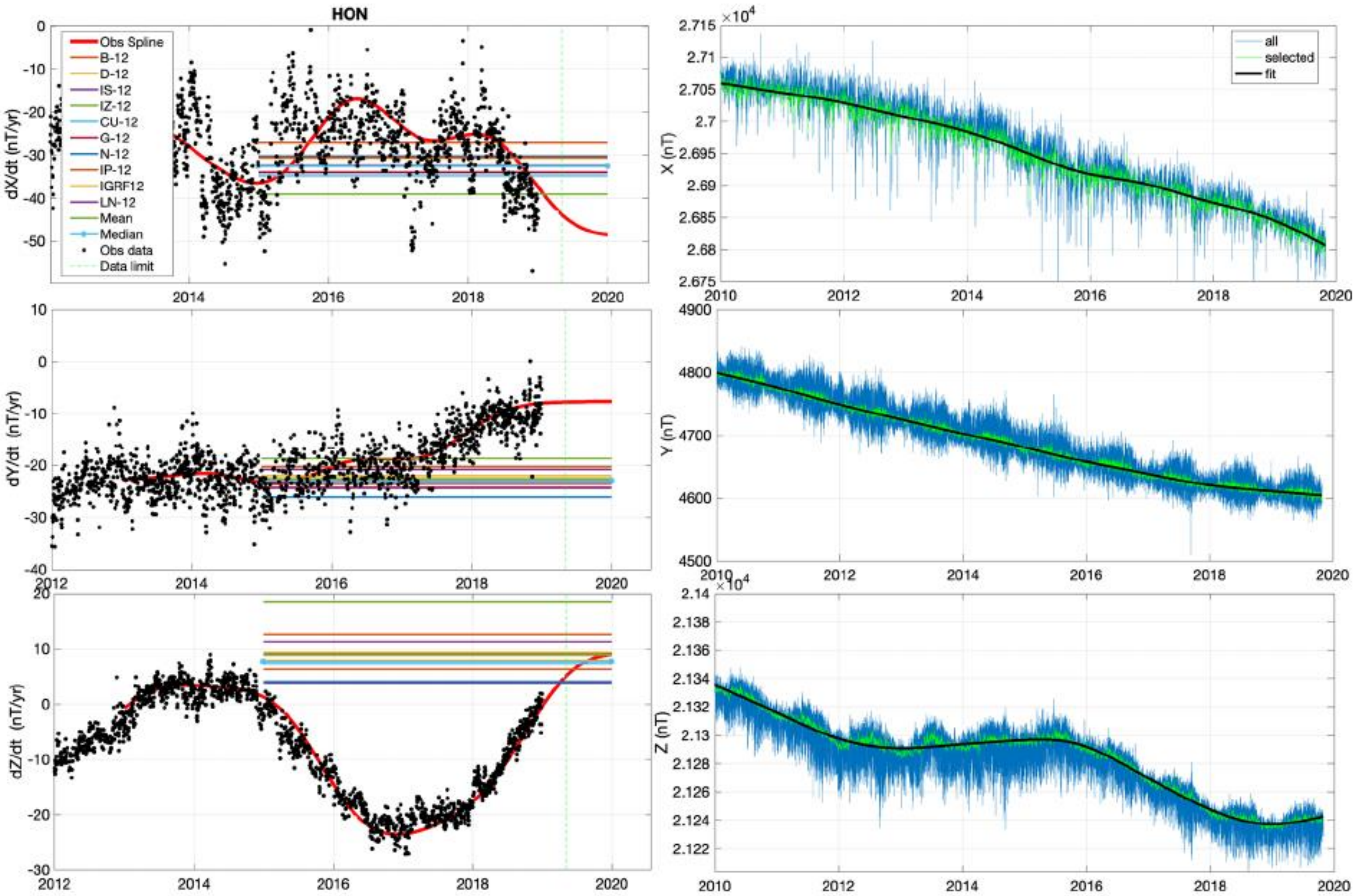


Fig. 12 IGRF12 retroactive SV comparison at Honolulu (HON). Left panels show the observatory annual differences of daily mean values (black), annual spline difference curve (red) and IGRF12 candidate predictions for the dB_x/dt (top), dB_y/dt (middle), and dB_z/dt (bottom) components in the NEC frame. Right panels show the original observatory data (blue), data after selecting for geomagnetically quiet periods (green), and fitted spline curve (black) for the B_x (top), B_y (middle) and B_z (bottom) components

Alken et al, EPS, 73:48, 2021

Analysis of IGRF-12 forecast (3/4)

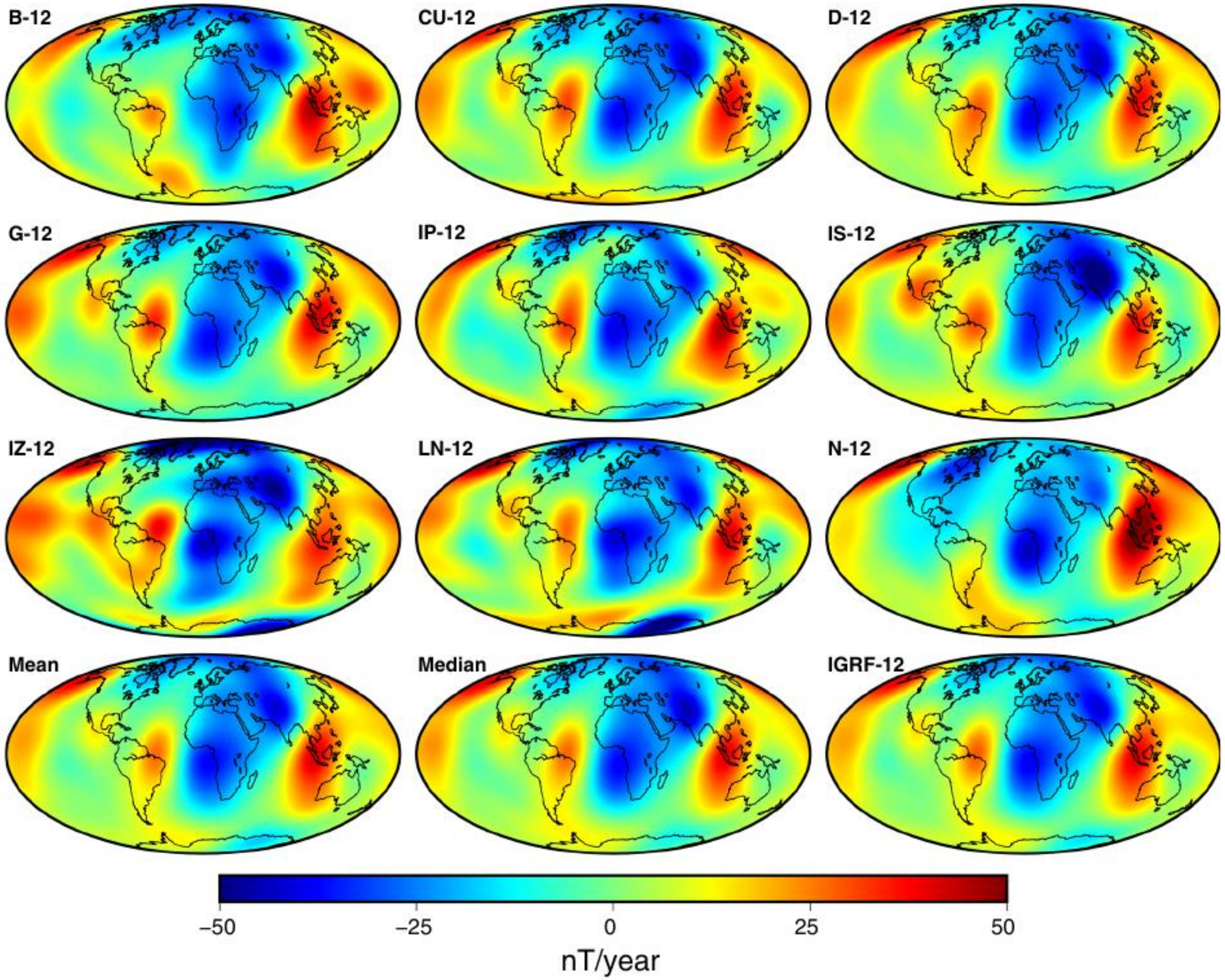


Fig. 13 Spatial map differences of dB_Z/dt (in nT/year) between IGRF-12 secular variation candidates and final IGRF-13 secular variation model over the 2015.0 to 2020.0 time period. We additionally include spatial map differences (against IGRF-13) of the mean and median of all IGRF-12 candidates, as well as the final IGRF-12 SV model in the bottom row

Analysis of IGRF-12 forecast (4/4)

Table 6 Root-mean-square differences in nT/year between observatory-derived secular variation splines and IGRF-12 candidates over the 2015–2020 time period

2015–2020	B-12	CU-12	D-12	G-12	IP-12	IS-12	IZ-12	LN-12	N-12	M	M_{med}	IGRF-12
dB_x/dt	11.76	12.10	11.64	11.53	11.20	11.68	12.41	11.65	12.81	11.47	11.31	11.47
dB_y/dt	9.35	11.22	11.24	10.92	10.64	12.99	12.04	11.05	10.37	10.71	10.87	10.75
dB_z/dt	18.42	19.2	18.54	17.78	17.33	19.73	21.60	19.41	22.16	18.39	18.03	18.50

The lead institute letter codes are provided in Table 1. LN refers to LPG Nantes which was not a lead institute for IGRF-13

- The two best performing forecasts over 2015-2020 combined data observations with physics-based modeling of core dynamics
- SV forecasts ***could*** benefit from physics-based modeling, especially as methodologies improve in the coming years
- The median model (Mmed) out-performed many of the individual candidates, illustrating the benefits of international collaborations

2. Status of data available for field modeling

Status of data available for field modeling

- Swarm
- CSES (Yang et al, JGR, 126(4), 2021)
- ePOP (Miles et al, Geosci. Instr. Met. Data Sys. 8, 2019)
- Platform magnetometers
  - DMSP (Alken et al, EPS, 72(49), 2020)
  - Cryosat-2 (Olsen et al, EPS, 72(48), 2020)
  - GRACE-FO (Stolle et al, EPS, 73(51), 2021)
- Ground network (observatories and variometers)

3. Spatial uncertainty of IGRF models

Spatial uncertainty of IGRF models

PROBLEM

- Call for the IGRF-13 candidate models requested uncertainties in *spectral* terms on the Gauss coefficient which a few teams provided

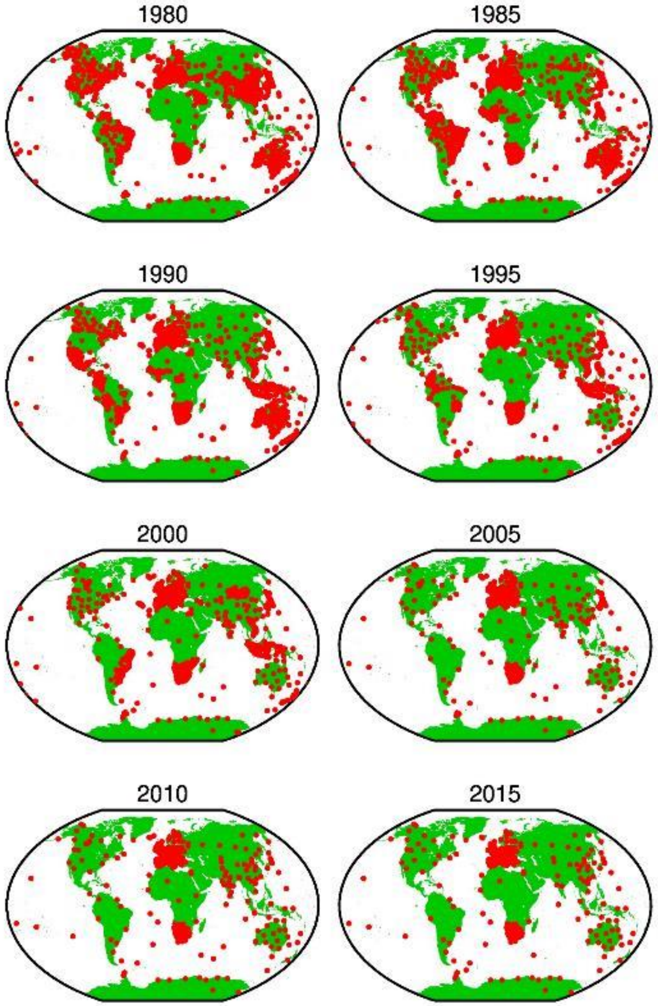
- However, most users seek *spatial* information, particularly declination and inclination which are non-linear operations of the X, Y and Z components.

AIMS

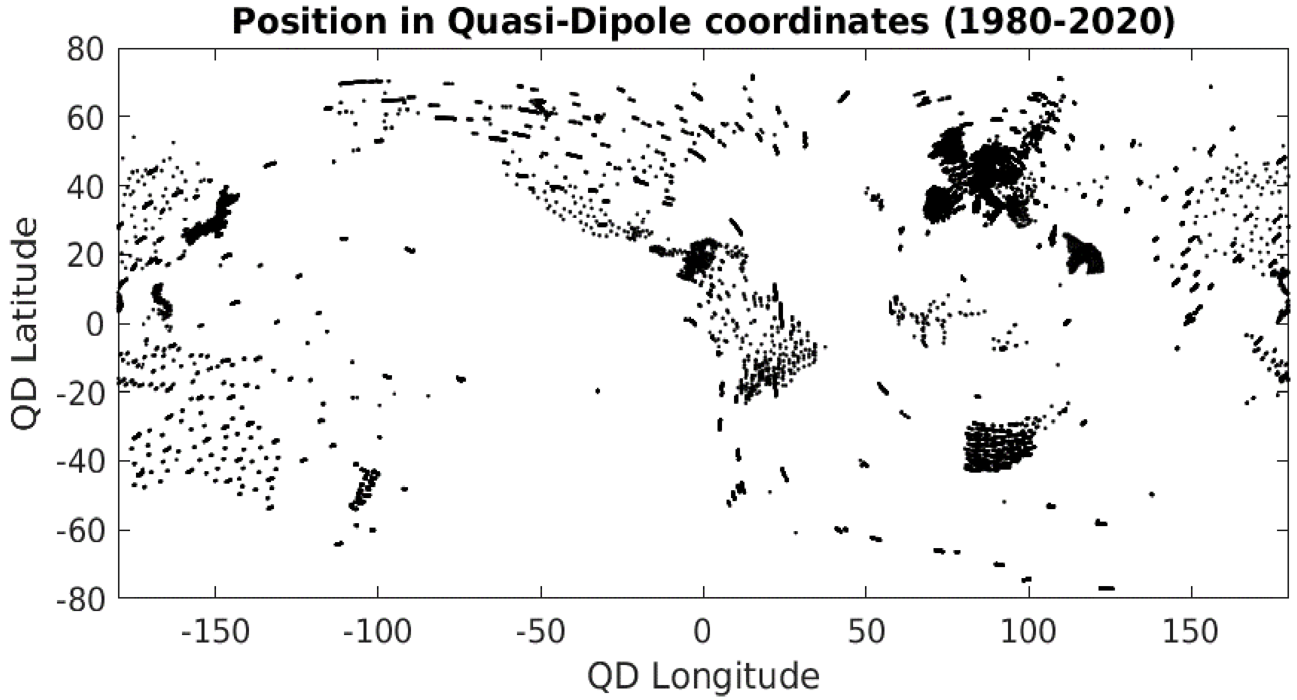
- Estimate the large-scale spatial error of the IGRF to provide indicative values to users illustrating where the magnetic components have larger uncertainties.

- Errors are based on the globally averaged misfit of IGRF to ground-based measurements at repeat stations and annual means at observatories since 1980 (~20K points available)

Repeat station & ground observatories

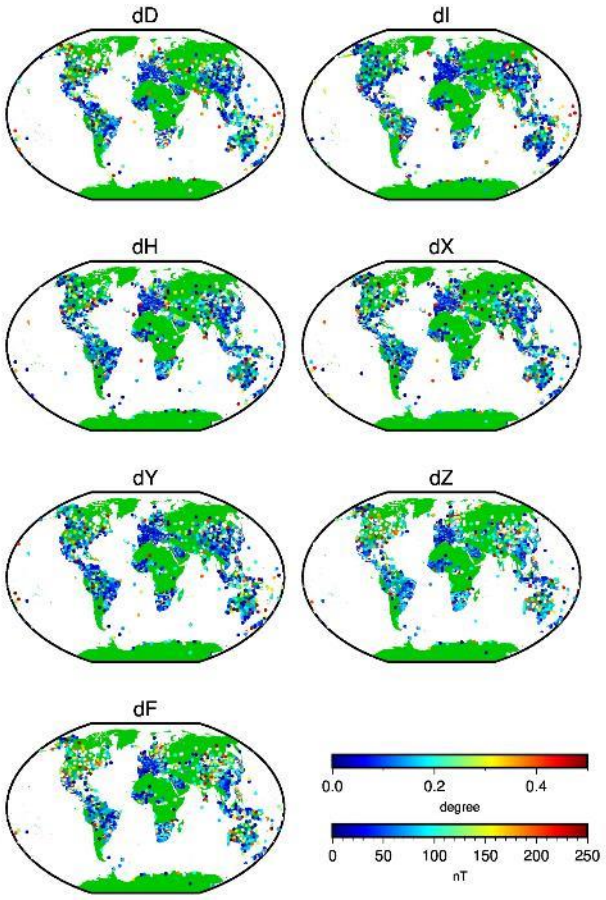


Repeat station and ground observatories

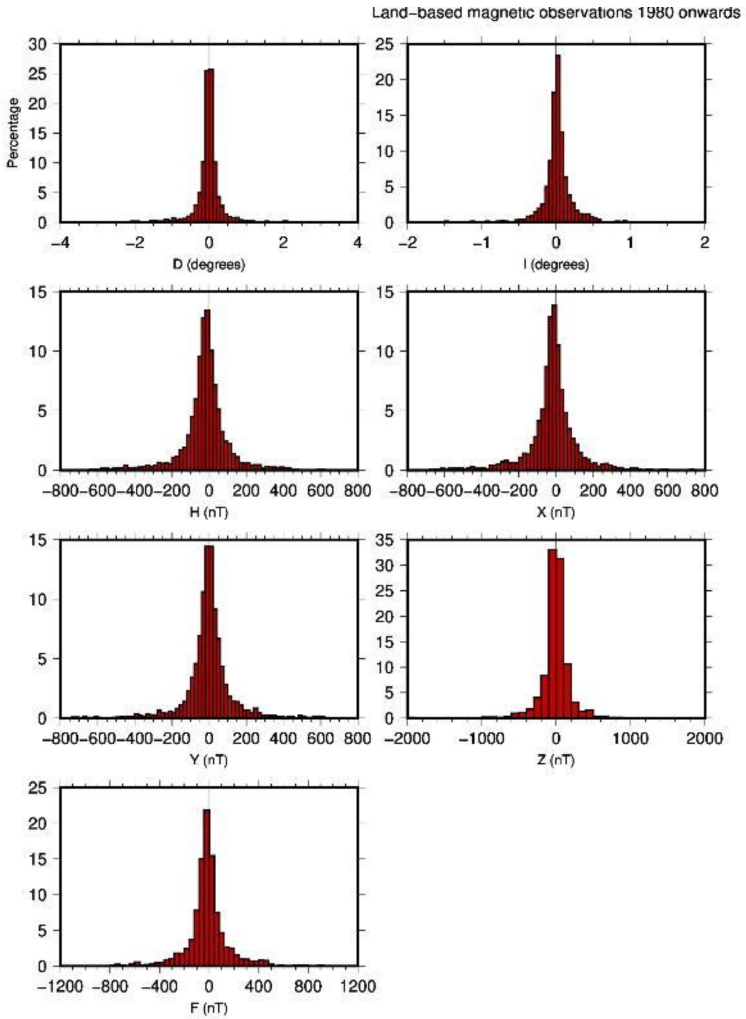


Quasi-dipole location over time

Residuals to IGRF



Spatial variation



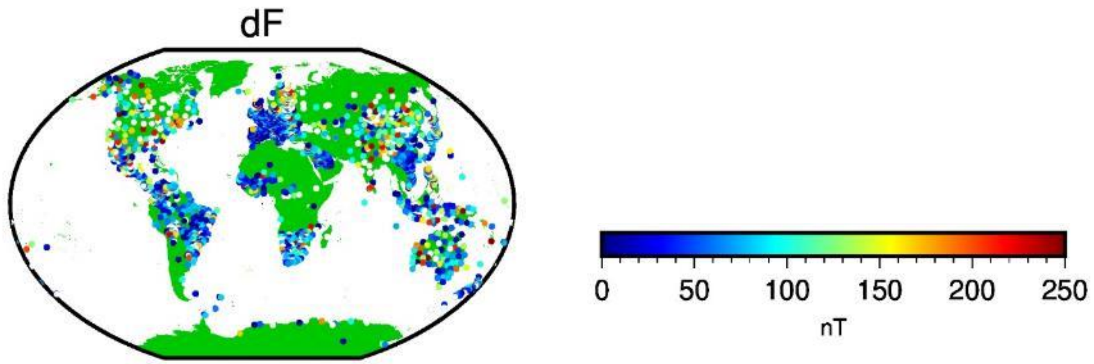
Histogram of residuals

	#data	Std dev	95.4% CI
D(°)	17411	0.39	0.78
I(°)	18237	0.29	0.50
X	16280	143	317
Y	16311	135	291
Z	18133	292	424
F	18314	178	429

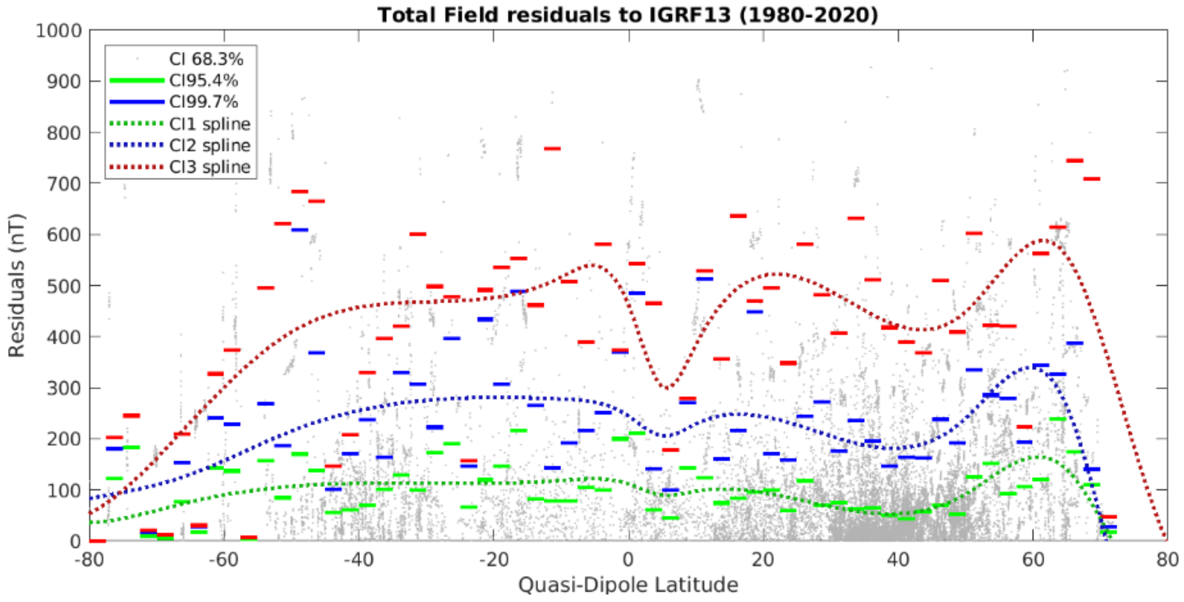
Std Dev & 2σ equivalent CI

Key points

- IGRF model fits measured ground data very well
- Histograms have mean of ~0 in all components
- The **standard deviation** of the residuals in **F is <180 nT**
- There is **not a strong latitudinal control:**
    - primarily due to the quiet-time reduction
    - may be a function of the sparsity of the ground data available too
- As external field effects are reduced, most differences are **probably local and geological**
- If *useful*, can publish these estimates – happy to collaborate with IAGA V-MOD colleagues
- Poster with more information in *Session 1.4*



Total Field residuals for all data

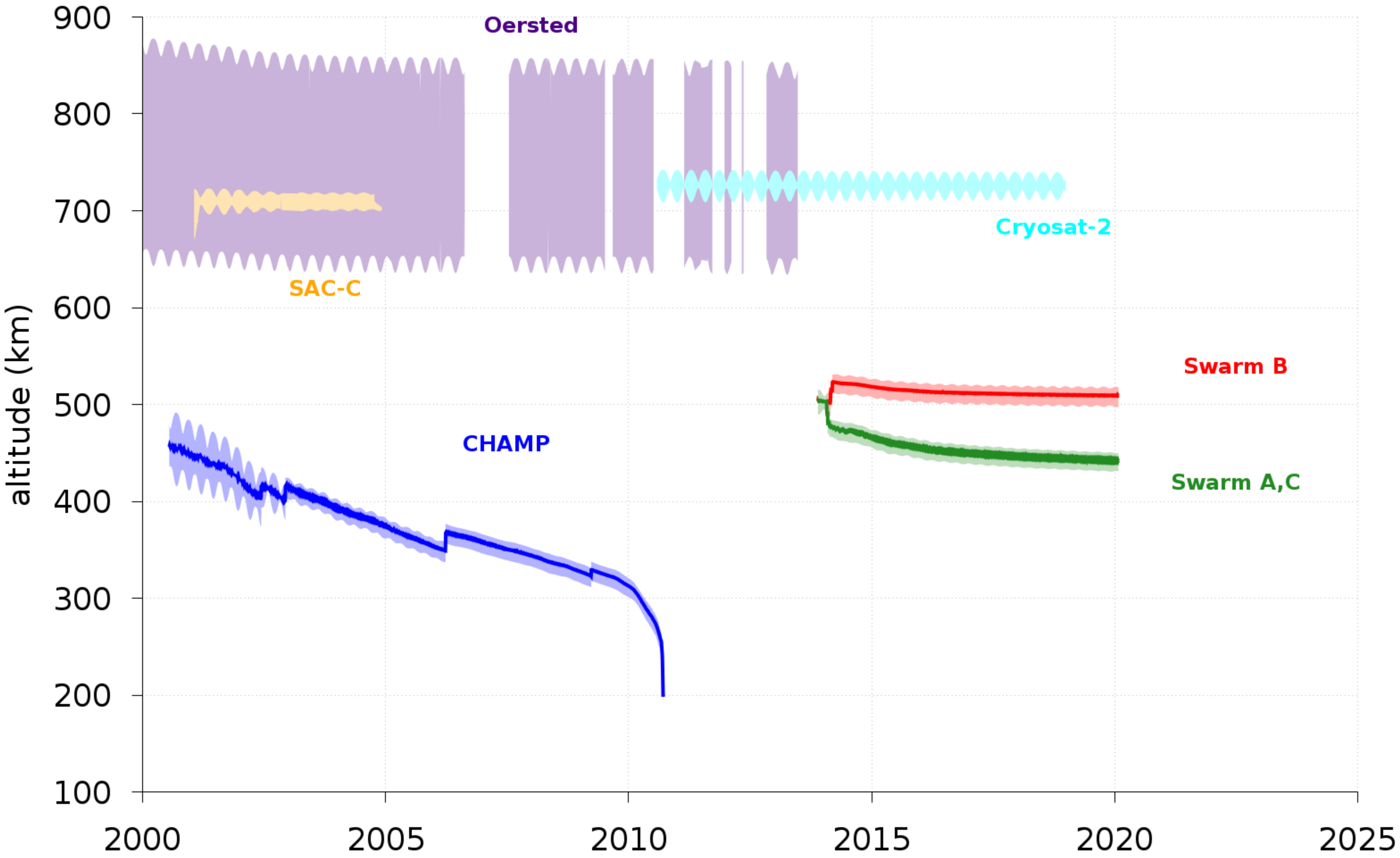


Total Field residuals with QD latitude

4. Possible revisit of DGRF-2010

Possible revisit of DGRF-2010?

- DGRF-2010 was based on input from 7 candidate models (see *Thebault et al, EPS, 67:112, 2015*)
- CHAMP provided the primary vector data from space
- Supplemented by scalar data from Oersted
- Additional vector data from ground observatory network
- In recent years, new "platform" satellite datasets have emerged
  - Cryosat-2
  - GRACE
  - DMSP



Oersted
Cryosat-2
SAC-C
Swarm B
CHAMP
Swarm A,C
altitude (km)
900
800
700
600
500
400
300
200
100
2000
2005
2010
2015
2020
2025

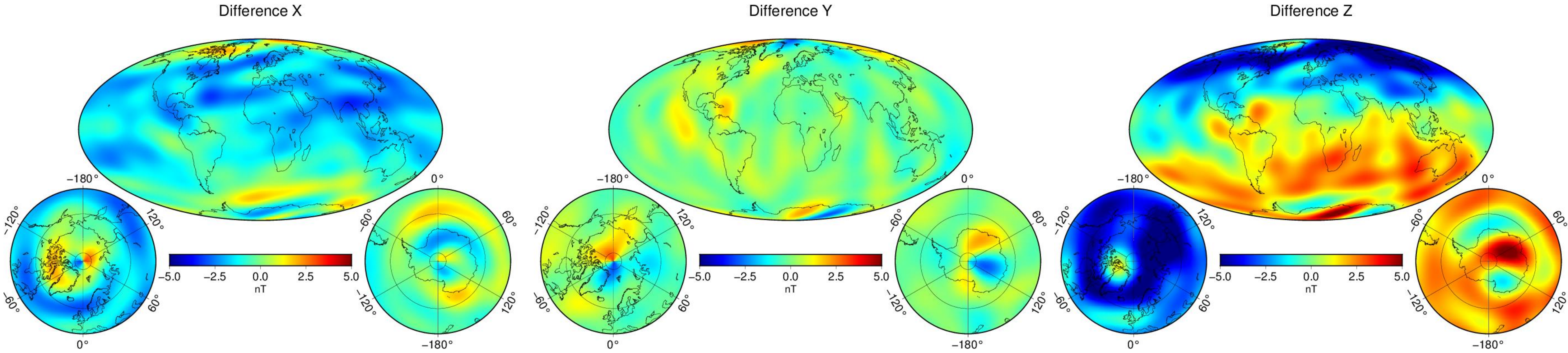
DGRF (Definitive Geomagnetic Reference Field)

- Based on best available datasets around epoch of interest and are therefore unlikely to be improved
- However in the case of DGRF-2010, there are new datasets available now which were not available to the IGRF-12 task force which may be relevant
- The IGRF-14 task force could decide to revisit DGRF-2010 if they deem it worthwhile

A simple test model (P. Alken)

- I constructed a test model using CHAMP and Cryosat-2 data between 2008.5 and 2011.5
- SH degree and order 15
- Quadratic Gauss coefficients to model MF, SV and SA
- Cryosat-2 data was processed and calibrated by N. Olsen (*Olsen et al, EPS, 72:48, 2020*)
- Standard quiet-time geomagnetic data selection
  - LTAN/LTDN between 22:00 and 05:00
  - Kp <= 2
  - |dRC/dt| <= 3 nT/hour
  - IMF By in [-6,6] nT
  - IMF Bz in [0,6] nT
- MF7 and CHAOS-6 magnetospheric models were removed from satellite data prior to fitting
- Gauss coefficients at 2010.0 truncated to degree 13 and then used in place of DGRF-2010 coefficients
- Model called **TESTIGRF-13**

Difference maps (IGRF-13 and TESTIGRF-13 at 2010.0 on Earth's surface)



Residual statistics

CHAMP (2009-2010)	N	μ IGRF-13	σ IGRF-13	μ TESTIGRF-13	σ TESTIGRF-13
X	191591	-0.93	4.36	0.12	4.28
Y	191591	-0.37	4.07	-0.36	4.05
Z	191591	-0.27	5.31	-0.37	5.04
F	191591	-1.72	3.89	-0.03	3.77

Cryosat-2 (2010-2011)	N	μ IGRF-13	σ IGRF-13	μ TESTIGRF-13	σ TESTIGRF-13
X	28731	2.19	5.90	2.86	5.92
Y	28731	-0.61	6.04	-0.61	5.97
Z	28731	-0.41	7.70	-0.49	7.65
F	28731	1.39	4.98	2.45	4.98

5. Report on WDMAM

6. IAGA 2023 sessions

Proposed sessions in 2023

- Satellite-based geomagnetic field measurements and modeling (jointly V-OBS)
  - Convenors: Hulot, Alken
- Modeling the geomagnetic field and its secular variation (jointly with Div I)
  - Convenors: W. Brown
- Studies of the lithospheric field
  - Convenors: J. Dyment

7. Any other business