IAGA V-MOD BUSINESS MEETING

Prague, Czech Republic

Wed 24th June 2015

Draft Agenda

0. Acceptance of draft agenda
1. Status of data available for field modelling
2. Report on IGRF-12
3. Report on WDMAM, version 2
4. Election of new co-chair
5. Suggestions for sessions at IAGA 2017 in Cape Town
6. Any other business

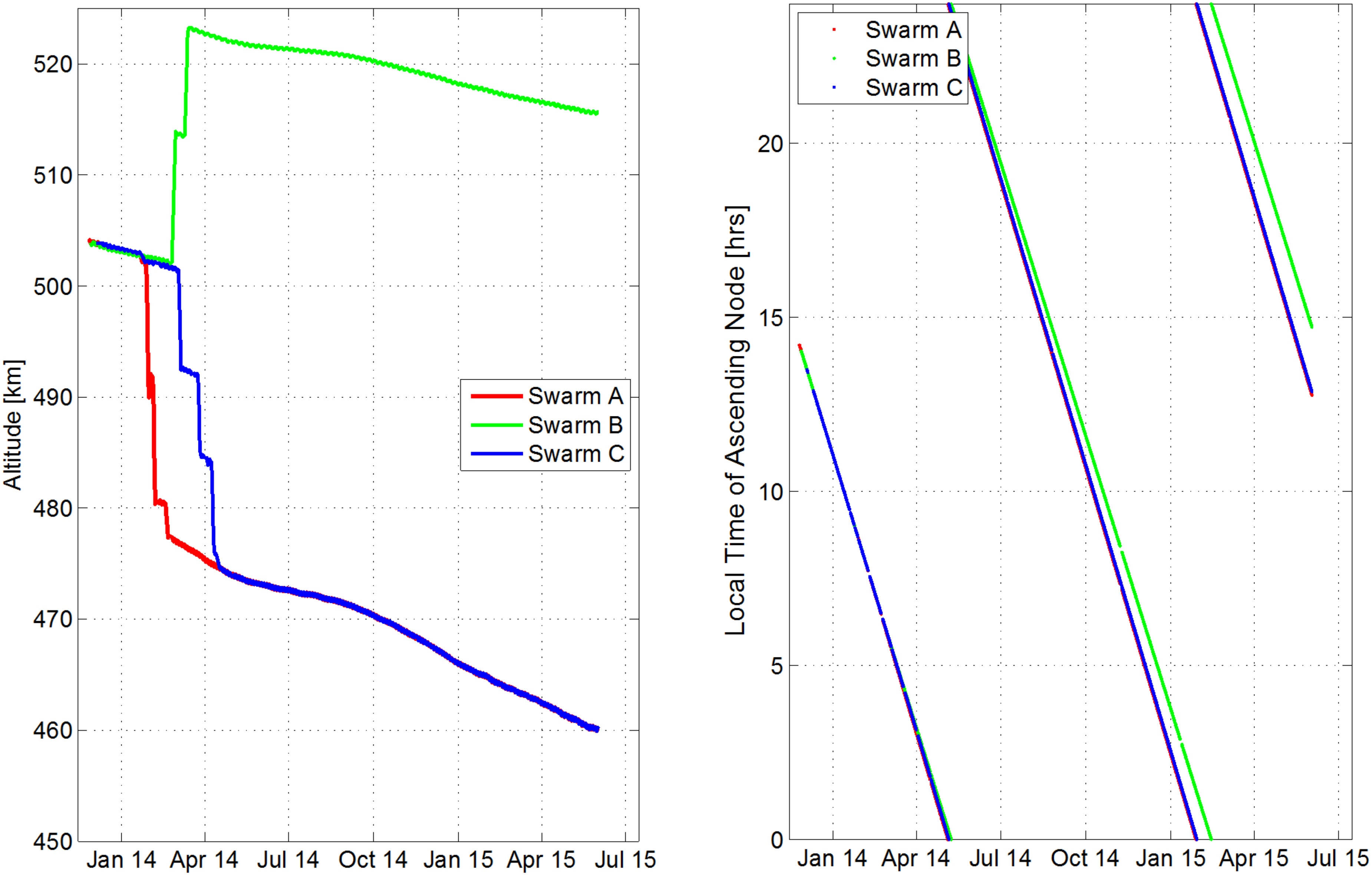
1. Data available for field modelling

Swarm

Credit: ESA

- Launched 22nd November 2013

Swarm: Evolution of constellation



Swarm magnetic field data

- Very well suited for deriving geomagnetic reference field models: e.g. was crucial for IGRF-12, epoch 2015 and SV 2015-2020.

- Has also already been used to derive high resolution field models (e.g. Swarm Initial Field Model, Olsen et al., 2015, GRL)

- All Swarm Level 1b and Level 2 products are freely available by FTP from ESA

- For the latest operational updates on status of satellites, data releases etc. see ESA's Swarm webpage

https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/swarm

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What is Swarm?

Swarm is the fifth Earth Explorer mission approved in ESA's Living Planet Programme, and was successfully launched on 22 November 2013.

The objective of the Swarm mission is to provide the best-ever survey of the geomagnetic field and its temporal evolution as well as the electric field in the atmosphere using a constellation of 3 identical satellites carrying sophisticated magnetometers and electric field instruments.

Latest Mission Operations News

Swarm Total Electron Current products

18 June 2015

The production of the Total Electron Content (TEC) data has started on 8 June 2015. The description of these products and scientific quality validation is documented here.

Read more

Swarm - B_NEC values fixed in a new set of corrected magnetic data

21 May 2015

A problem was found in the B_NEC values of the recently corrected Swarm magnetic data. For this reason, the MAGx_LR_1B products have been re-computed and made available again on the ESA FTP server in the "Current" folder.

Read more

Swarm Ionospheric Bubble Index and Field-Aligned Current products

14 May 2015

From 09 May 2015 the production of the Ionospheric Bubble Index (IBI) product has started, and the production of

Missions

- Missions Home
- ESA EO Missions
  - Sentinel-1
  - Swarm
    - Product Data Handbook
    - Data Access
    - FAQs
    - News
  - Proba-V
  - CryoSat
  - SMOS
  - GOCE
  - Envisat
  - Proba-1
  - ERS
- ESA Future Missions
- 3rd Party Missions
- ESA Earth Observation Campaigns Data
- ESA/EUMETSAT
- ESA Mission Continuity
- ESA Mission News
- ESA User Services News

Useful Links

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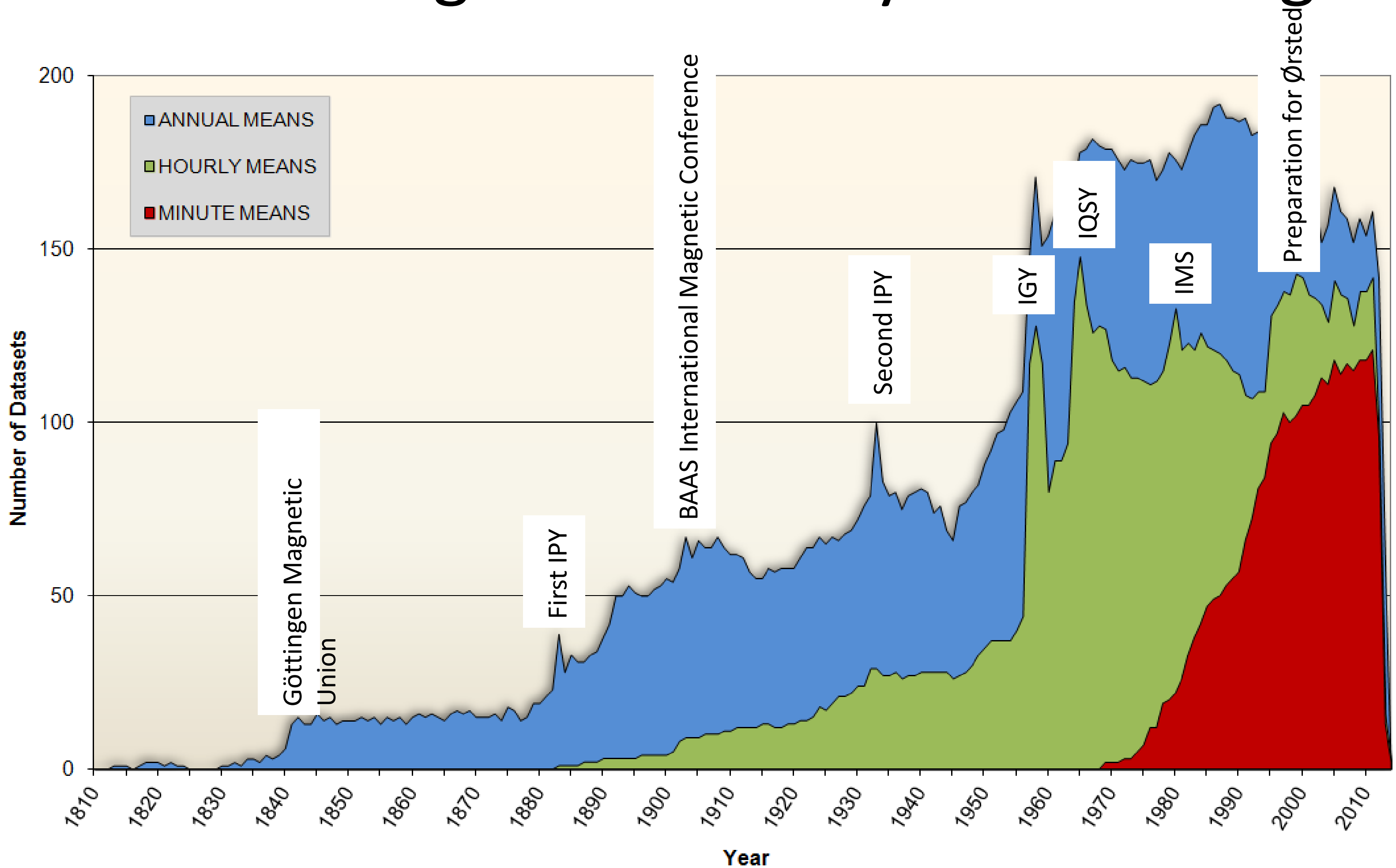
Other satellite data

- Ørsted : No data retrieved since mid-2013.
  Now tumbling, v. difficult to contact.

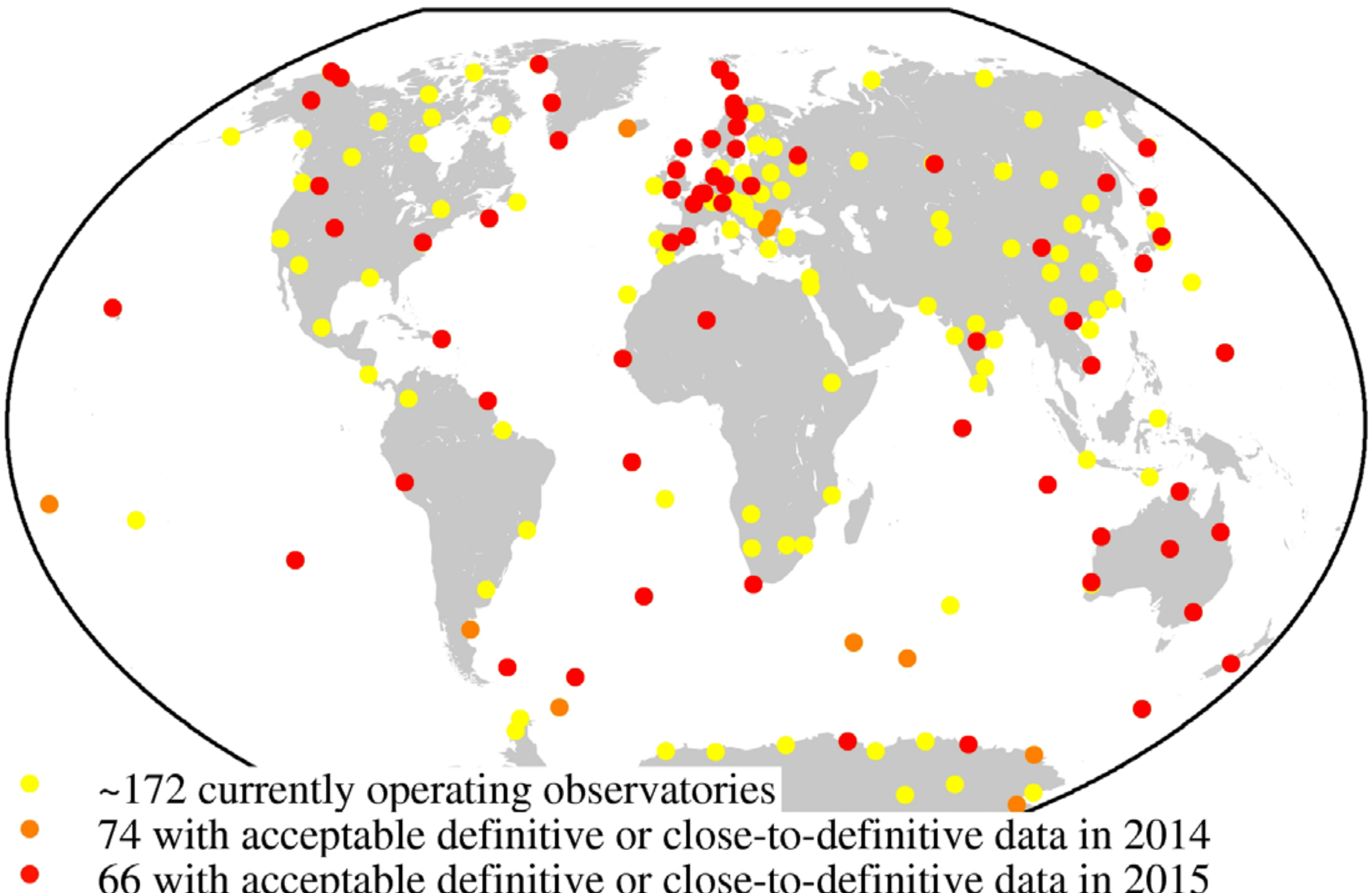
- DMSP: Used by NGDC/NOAA for field modelling
  Magnetic field data freely available but not
positions

Ground observatories
WDC Edinburgh observatory data holdings



IPY – International Polar Year IGY – International Geophysical Year
IQSY – International Quiet Sun Year IMS – International Magnetospheric Study
BAAS – British Association for the Advancement of Science

Observatory locations and timeliness of data release for use in modelling



- Checked OBS hourly means derived by BGS; available as ESA L2 AUX product: **AUX_OBS_2**
(From L2PS server as well as ftp://ftp.nerc-murchison.ac.uk/geomag/smac/AUX_OBS_2/)

2. Report on IGRF-12

The International Geomagnetic Reference Field

"Every five years, the International Association of Geomagnetism and Aeronomy (IAGA) releases the International Geomagnetic Reference Field (IGRF):

1. *A standard model of the main field (MF) and its predicted secular variation (SV) for the following 5 years.*
2. *A revision of the previous IGRF model into a definitive geomagnetic reference model describing the field up to the end of the previous epoch."*

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

SPECIFICATIONS

- 1) Internal field (main field) for 2015.0 to spherical harmonic (SH) degree and order 13.
- 2) Predicted average secular variation for 2015.0-2020.0 to SH degree and order 8 .
- 3) Internal field (main field) for 2010.0 to SH degree and order 13.

RULES

- Each team of workers should submit only one candidate model per product.
- Every lead institution can have only one team, and every individual can lead only one team.
- In order to facilitate collaboration (for example sharing of pre-processed data), it is possible for an individual to be a member of several teams.

The Definitive Geomagnetic Reference Field 2010

Seven institutions submitted candidate models for epoch 2010.0 in October 2014.
They primarily used measurements from the satellite mission Oersted, CHAMP, SAC-C and Swarm A, B, and C, and data from the magnetic observatories.

DGRF candidate models for main field epoch 2010				
Team	Model	Organization	Data	Comments (parent model etc.)
A	DGRF-2010-A	BGS	Ørsted; CHAMP; Swarm A, B, C; Observatory hourly means	Based on parent model using order 6 B-splines with 1 yr. knot spacing
B	DGRF-2010-B	DTU Space	Ørsted; CHAMP; SAC-C; Swarm A, B, C; Observatory monthly means	Based on CHAOS-5 using order 6 splines with 6 months spacing
C	DGRF-2010	ISTerre	Ørsted; SAC-C; CHAMP; Swarm B observatory monthly mean	Based on COV-OBS.x1 using order 4 B-splines with 2 years spacing
D	DGRF-2010-D	IZMIRAN	CHAMP 2009.0-2010.75 no data selection but numerical fitlering	Spherical Harmonics for each day then linear regression centered on 2010.0
E	DGRF-2010-E	NGDC-NOAA	CHAMP	Based on parent model using quadratic expansion
F	DGRF-2010-F	GFZ USTHB/EOST	CHAMP from 2009.0 to 2011.0 observatory hourly means	Based on parent model using order 6 B-splines with 6 months spacing
G	DGRF-2010-G	NASA/GSFC	Ørsted; CHAMP; SAC-C observatory hourly means	Based on CM5 using order 5 B-splines with 6 months spacing

Table 1 Summary of DGRF-2010 candidate models submitted to IGRF-12.

IGRF-12 results from the successful cooperation between scientists involved in modeling the magnetic field, the institutions archiving and disseminating the ground magnetic field data, and the national and the space agencies who distribute well documented magnetic satellite data from the satellite missions.

The Definitive Geomagnetic Reference Field 2010

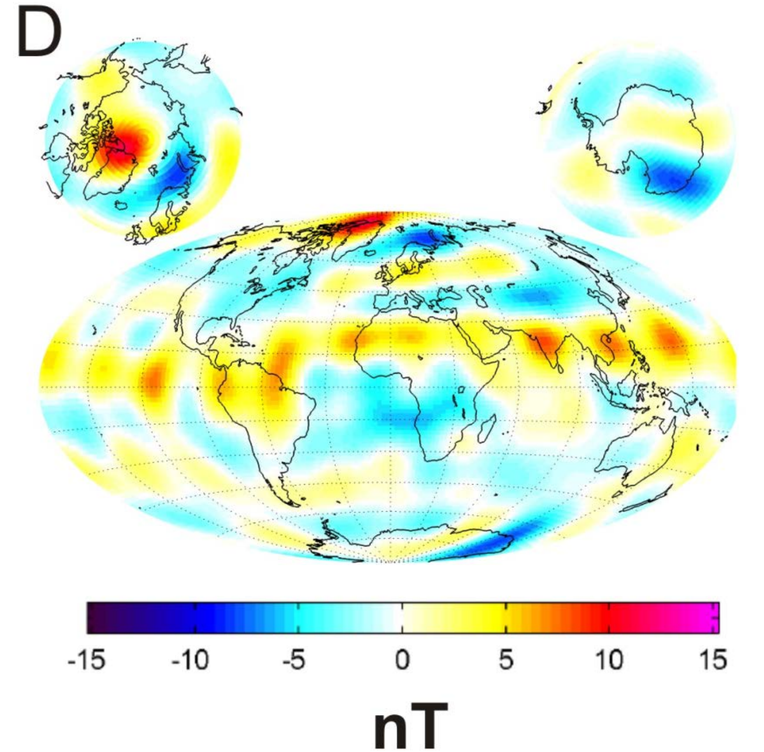
${}_{i,j}R$ / nT	A	B	C	D	E	F	G	M	M_{med}
A	0.00	2.76	6.61	4.01	2.40	2.55	4.92	1.97	1.70
B	2.76	0.00	7.06	4.91	2.04	2.37	5.38	2.50	1.96
C	6.61	7.06	0.00	7.28	6.72	7.66	5.81	5.45	5.99
D	4.01	4.91	7.28	0.00	4.27	4.52	5.66	3.53	3.72
E	2.40	2.04	6.72	4.27	0.00	2.42	4.81	1.92	1.51
F	2.55	2.37	7.66	4.52	2.42	0.00	5.47	2.68	2.18
G	4.92	5.38	5.81	5.66	4.81	5.47	0.00	3.69	4.19
Mean Diff	3.88	4.09	6.86	5.11	3.78	4.17	5.34	3.10	3.04

Table 2 RMS vector field differences ${}_{i,j}R$ in units nT between DGRF-2010 candidate models and also between candidates and the arithmetic mean reference models M and median reference model M_{med} in the rightmost columns. The bottom two rows are simple arithmetic means ${}_{i}\overline{R}$ of the ${}_{i,j}R$ where the means include all candidates.

The evaluation relied primarily on statistical analyses. The IGRF task force relied on: residual mean square analysis, power spectrum differences, azimuthal power spectra, sensitivity matrix, spherical harmonic correlation, candidate model differences in space, …

Then evaluators analyzed the differences using the candidate model descriptions prepared by each team.

The Definitive Geomagnetic Reference Field 2010



- Differences between candidate models are largest for the dipole term (internal/external field separation).
- Candidate model C corrected for the internal induced field (model C)
- Candidate model D considered all large-scale structures.

Some teams have a different interpretation of what IGRF should be used for. In most cases, the differences are explained by solid but different scientific choices.

The Geomagnetic Reference Field 2015

Nine institutions prepared candidate models for epoch 2015.0

IGRF candidate models for main field epoch 2015				
Team	Model	Organization	Data	Comments (parent model, propagation to 2015)
A	IGRF-2015-A	BGS	Ørsted; CHAMP; Swarm A, B, C; Observatory hourly means	Based on parent model evaluated in 2015.0 extrapolation from steady core flow hypothesis
B	IGRF-2015-B	DTU Space	Ørsted; CHAMP; SAC-C; Swarm A, B, C; Observatory monthly means	Parent CHAOS-5 evaluated in 2015.0 linear extrapolation from 2014.0
C	IGRF-2015-C	ISTerre	Ørsted; SAC-C; CHAMP; Swarm B observatory monthly mean	Parent COV-OBS.x1 model evaluated in 2015 using forward integration of a stochastic model
D	IGRF-2015-D	IZMIRAN	Swarm A, B, and C vector data Nov-2013 to Sep-2014, no data selection	Parent model evaluated in 2015.0 linear extrapolation
E	IGRF-2015-E	NGDC-NOAA	Ørsted; Swarm A, B, C	Parent model evaluated in 2015.0 linear extrapolation from 2014.3
F	IGRF-2015-F	GFZ USTHB/EOST	Swarm A, B, C; observatory hourly means	Parent model evaluated in 2015.0 lineral extrapolation from 2014.5
H	IGRF-2015-H	IPGP CEA/CNES	Swarm A, B, C Nov-2013 to Sep-2014 only ASM experimental vector data	Parent model evaluated in 2015.0
I	IGRF-2015-I	LPG Nantes CNES	Swarm A and C Nov-2013 to Sep-2014	Parent model evaluated in 2015.0 linear extrapolation from 2014.3
J	IGRF-2015-J	ETH Zurich GFZ	Swarm C; Dec-2013 to Sep-2014	Parent model evaluated in 2015.0 linear extrapolation

Table 3 Summary of IGRF-2015 candidate models submitted to IGRF-12.

The number of institutions participating in IGRF-12 was larger than for any previous generation of IGRF.

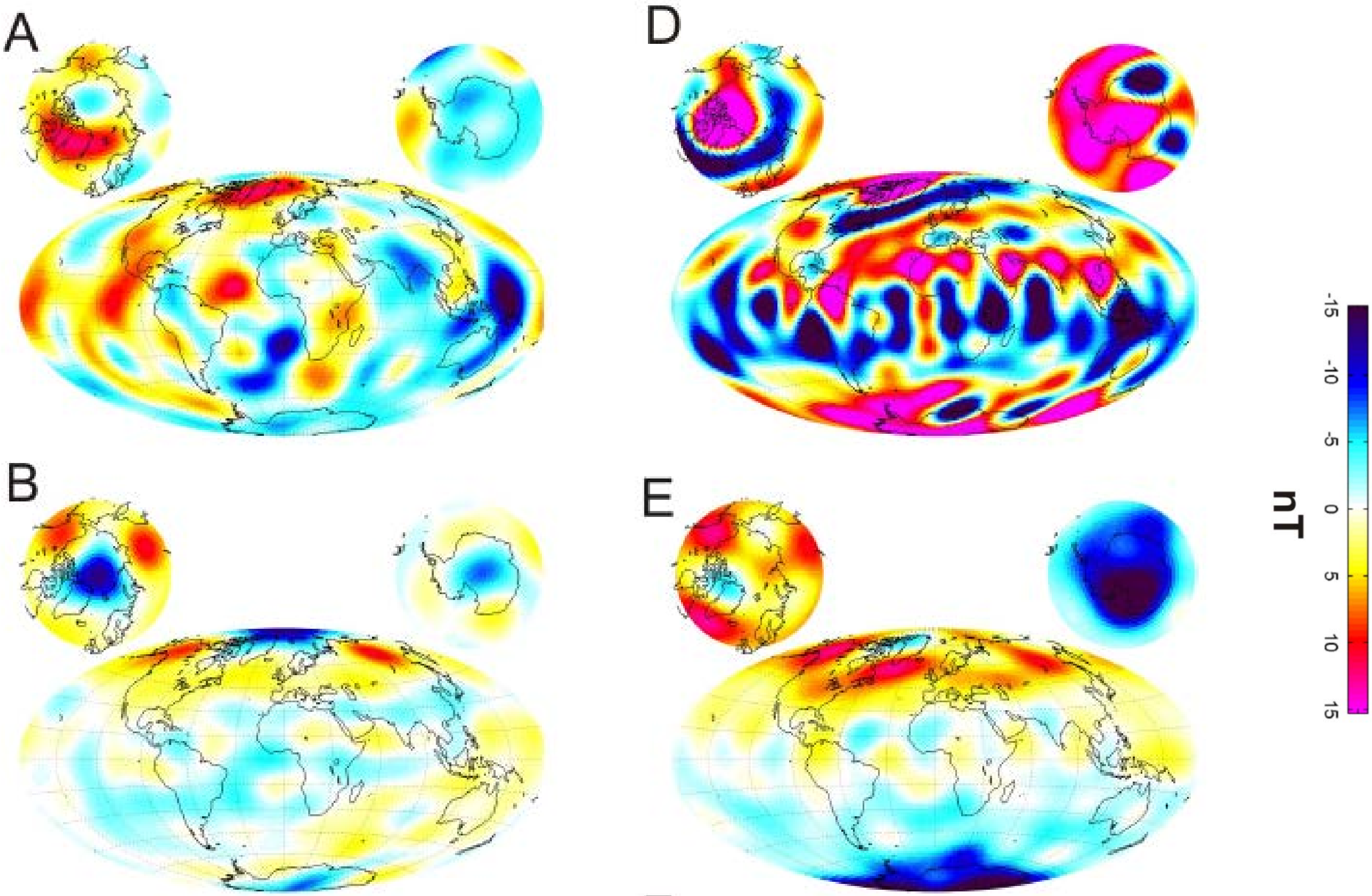
The Geomagnetic Reference Field 2015

${}_{i,j}R$ / nT	A	B	C	D	E	F	H	I	J	M	M_{med}
A	0.0	6.8	12.1	14.1	7.3	6.3	9.1	10.3	16.2	6.2	5.8
B	6.8	0.0	9.8	13.3	4.8	5.1	5.4	9.3	15.3	3.8	3.2
C	12.1	9.8	0.0	17.0	12.5	10.1	10.9	11.8	15.4	8.8	8.9
D	14.1	13.3	17.0	0.0	14.3	12.9	16.1	14.5	18.4	11.8	12.6
E	7.3	4.8	12.5	14.3	0.0	6.5	7.0	9.9	16.3	5.8	5.2
F	6.3	5.1	10.1	12.9	6.5	0.0	7.6	9.2	15.0	4.1	3.5
H	9.1	5.4	10.9	16.1	7.0	7.6	0.0	11.8	17.3	7.0	6.4
I	10.3	9.3	11.8	14.5	9.9	9.2	11.8	0.0	14.9	7.4	7.8
J	16.2	15.3	15.4	18.4	16.3	15.0	17.3	14.9	0.0	12.9	13.8
Mean Diff	10.3	8.7	12.4	15.1	9.8	9.1	10.6	11.5	16.1	7.5	7.5

Table 4 RMS vector field differences ${}_{i,j}R$ in units of nT between IGRF-2015 candidates and also between them and the arithmetic mean of all candidates M and the median M_{med}. The bottom row displays the mean of the RMS vector field differences between each candidate model and all other candidate models ${}_{i}\overline{R}$ from Eq. (8) labelled 'Mean Diff'.

RMS differences are larger for IGRF-2015 than for DGRF-2010 because magnetic field measurements were available till September 2014. All candidate models thus relied on some extrapolation to epoch 2015.0

The Geomagnetic Reference Field 2015



Differences to the arithmetic mean model show more complex features arising from differing extrapolation schemes and possible internal/external field separation issues.

Predicted secular variation for 2015.0 to 2020.0

Nine institutions prepared a candidate model for the predictive secular variation.

Predictive SV candidate models for epoch 2015-2020				
Team	Model	Organization	Data	Comments (parent model, propagation to 2015)
A	SV-2015-2020-A	BGS	Ørsted; CHAMP; Swarm A, B, C; Observatory hourly means	Based on core flow parent model evaluated and averaged SV from 2015.0 to 2020.0
B	SV-2015-2020-B	DTU Space	Ørsted; CHAMP; SAC-C; Swarm A, B, C; Observatory monthly means	Based on parent CHAOS-5 model evaluated from splines at 2014.0
C	SV-2015-2020-C	ISTerre	Ørsted; SAC-C; CHAMP; Swarm B observatory monthly mean	Based on parent ensemble COV-OBS.x1 model evaluated and averaged SV from 2015.0 to 2020.0
D	SV-2015-2020-D	IZMIRAN	Swarm A, B, C Nov-2013 to Sep-2014, no data selection	Natural Orthogonal Components (NOCs) estimated at 2014.7 (sept-2014)
E	SV-2015-2020-E	NGDC-NOAA	Ørsted; Swarm A, B, C	From parent model 1st order Taylor series with slope at 2015.0
F	SV-2015-2020-F	GFZ USTHB/EOST	Swarm A, B, C; observatory hourly means	From parent model evaluated and averaged SV from 2013.5 to 2014.5
G	SV-2015-2020-G	NASA UMBC		Geodynamo simulation and assimilation from CALS3K.2, gufm1, CM4, CHAOS-4+; average SV from 2015.0 to 2020.0
H	SV-2015-2020-H	IPGP LPG Nantes	Swarm A, B, C	Geodynamo simulation and assimilation from Swarm evaluated and averaged SV from 2015.0 to 2020.0
I	SV-2015-2020-I	LPG Nantes CNES	Swarm A and C Nov-2013 to Sep-2014	From parent model 1st order Taylor series with slope at 2014.3

Table 5 Summary of SV-2015-2020 candidate models submitted to IGRF-12.

- Five “mathematical” models
- Four “physical” models, two relying on core flow assumptions, two relying on geodynamo simulation and assimilation.

The mathematical models proposed SV centered on 2015.0 while the physically based models proposed an average over the full five years interval (centered on epoch 2017.5)

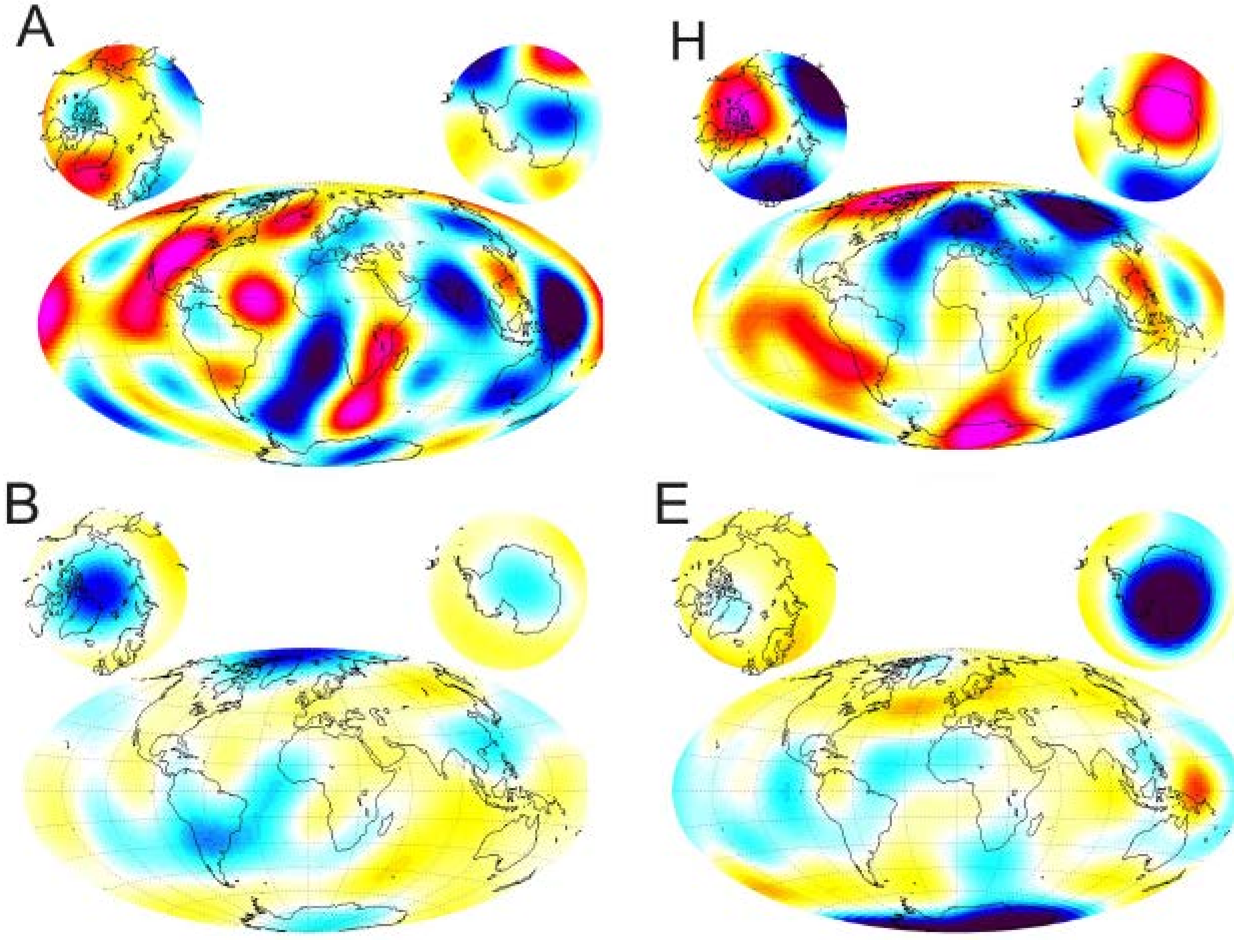
Predicted secular variation for 2015.0 to 2020.0

${}_{i,j}R$ in nT/yr	A	B	C	D	E	F	G	H	I	M	M_{med}
A	0.0	9.7	14.2	16.6	11.0	10.9	11.6	10.7	14.1	8.4	8.8
B	9.7	0.0	9.0	13.7	5.2	6.4	12.2	9.9	10.4	4.2	3.4
C	14.2	9.0	0.0	15.6	8.9	10.1	19.0	12.3	13.3	9.3	8.4
D	16.6	13.7	15.6	0.0	14.1	12.1	20.0	15.0	12.3	11.6	12.3
E	11.0	5.2	8.9	14.1	0.0	7.5	13.6	10.8	11.3	5.6	4.8
F	10.9	6.4	10.1	12.1	7.5	0.0	14.1	9.1	10.7	5.1	5.2
G	11.6	12.2	19.0	20.0	13.6	14.1	0.0	14.4	15.6	11.8	12.1
H	10.7	9.9	12.3	15.0	10.8	9.1	14.4	0.0	9.9	7.2	7.8
I	14.1	10.4	13.3	12.3	11.3	10.7	15.6	9.9	0.0	8.1	8.9
Mean diff	12.3	9.6	12.8	14.9	10.3	10.1	15.1	11.5	12.2	7.9	8.0

Table 6 RMS vector field differences ${}_{i,j}R$ in units nT/yr between SV-2015-2020 candidate models and also between these and the mean model M and the median model M_{med}. The final row labelled 'Mean Diff' is the mean ${}_{i}\overline{R}$ of the ${}_{i,j}R$ for each candidate or mean model.

Not surprisingly, the scatter of differences between the candidate models for SV-2015.0-2020.0 is larger than in the case of the main field.
However, there is no systematic separation between the 'mathematical' and 'physical' models.

Predicted secular variation for 2015.0 to 2020.0



Differences in space show small-scale residuals for physically based models (e.g. model A and H). This can be explained by the averaging over the five years interval.

Construction of IGRF-12

- In the past IGRF, fixed weights were allocated to the candidate models using information gleaned from the evaluation process.

- This time, a majority of the task force thought that the internal discrepancies between different groups of models were not sufficient to reject any of the models.

- It was argued that an application of the Huber weighting in space would be appropriate since the IGRF is mainly used for mapping purposes

$$\widetilde{\mathbf{x}}_{it+1} = \widetilde{\mathbf{x}}_{it} + \left(\mathbf{A}'\mathbf{W}_{it}\mathbf{A}\right)^{-1}\mathbf{A}'\mathbf{W}_{it}(\mathbf{A}\widetilde{\mathbf{x}}_{it} - \mathbf{B}),$$

With

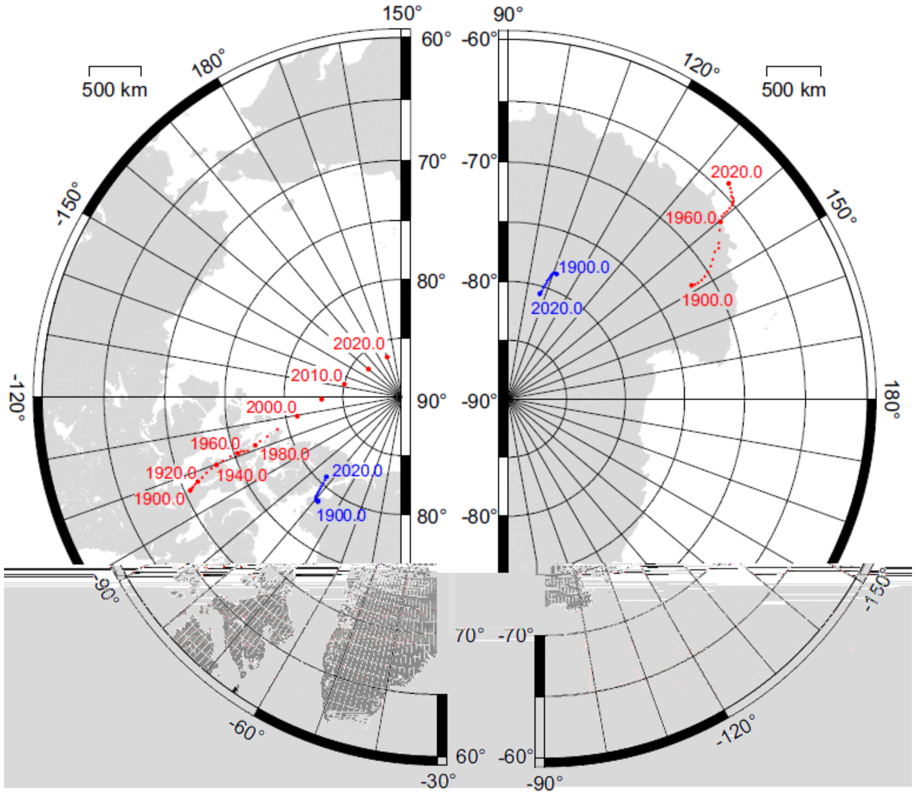
$$W_{it} = \begin{cases} 1 & \text{if } {}_i\bar{\epsilon}_{k,p} \leq c \\ c/{}_i\bar{\epsilon}_{k,p} & \text{if } {}_i\bar{\epsilon}_{k,p} > c \end{cases},$$

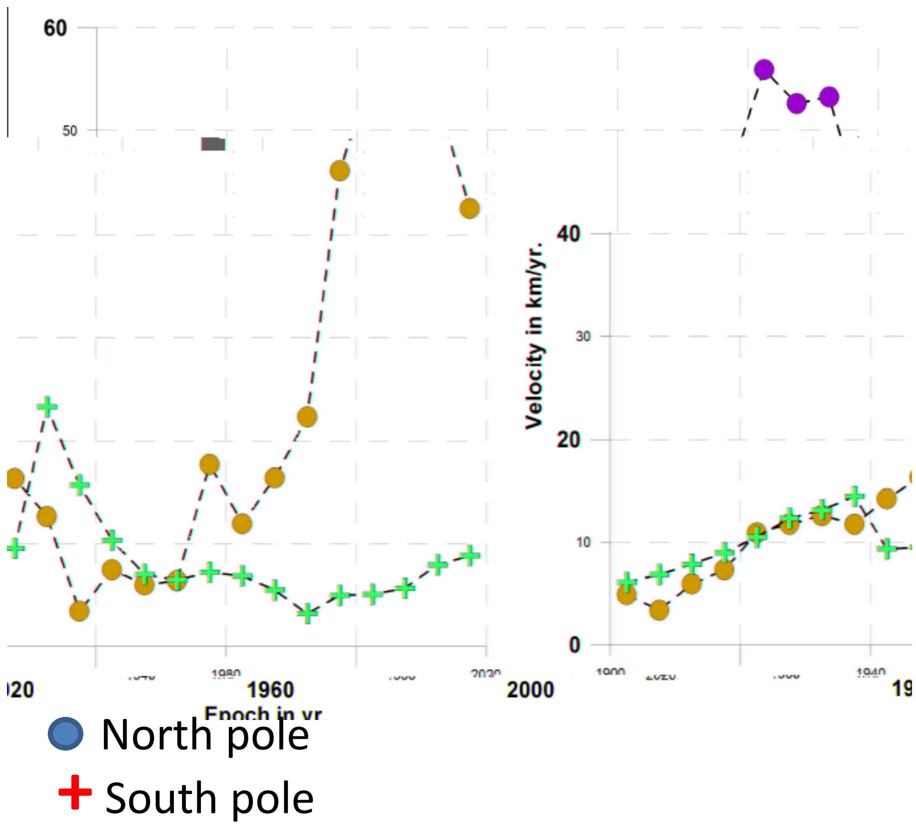
and c=1.345 the Huber constant.

Construction of IGRF-12

The weights were estimated iteratively for each magnetic field component of each candidate model. Here the weights are shown for **Br** for IGRF-2015.

Latest changes and possible future trends





Perhaps the most striking feature of IGRF-12 is that the North Magnetic Pole appears to have started a phase of deceleration with a velocity of about 53.2 km/yr in 2015 and a projected velocity of 42.6 km/yr in 2020.

Summary

- This is the first time IGRF receives so many candidate models.
- Candidate models relied both on mathematical and physical approaches.
- A robust weighting scheme was applied to the candidate models in space, as agreed by a vote of the IGRF-12 task force in December 2014.
- The Huber weighted mean IGRF-12 coefficients can be found in electronic (http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html) or print (Thébault et al., International Geomagnetic Reference Field: the twelfth generation, submitted to EPS) forms.

- Most of the candidate models are under review in *Earth Planets and Space*.
- Full details of the evaluation process are given in Thébault et al., Evaluation of candidate geomagnetic field models for IGRF-12, submitted to EPS.

The authors acknowledge the World Data Centers in charge of disseminating the observatory magnetic field measurements and ESA for providing prompt access to the Swarm L1b data.

Definition of IGRF:
An offer by F. Lowes

I would like to suggest one topic that could usefully be raised at the V-MOD meeting in Prague, or probably more practical, by discussion/questionnaire in writing afterwards.

The topic is the question of trying to define just what field(s) should be included in the IGRF in future. …I think that V-MOD should probably now have a serious discussion as to how to define what field(s) the IGRF should be trying to model.

If nothing else, ISO 16695-2 has "It is left to the producer of a model to specify which internal and external magnetic sources are included in (or excluded from) their model.”

At present IAGA IGRF documents refer to "Internal field (main field)". I would be happy to stick with this – (a) it has the qualification "internal" which is essential, and (b) I think "main field" is a clear pointer to the large-scale long-period electric currents produced by dynamo action in the core.

However it could perhaps be argued that "internal" should be expanded so as to EXPLICITLY exclude induced currents produced in the conducting core by time-varying externally-sourced fields, such as from the ring-current Dst, the ionosphere, and the field produced by global-scale ocean circulation.

Definition of IGRF:
An offer by F. Lowes

If you agree that this is an item that needs to be discussed IN ADVANCE OF IGRF-13, and if you think it would help, I could produce a short discussion paper for circulation after Prague.

Perhaps it would help if it were made clear that in practice any (expanded) "definition" is an AIM, and not a REQUIREMENT.

Each team should endeavour to produce a candidate model that was the best approximation that THAT TEAM could produce. If they used night-time data, but decided that they did not have sufficient information to estimate the ionospheric induced contribution, then that was their decision – no one would force them to use an estimate made by someone else.

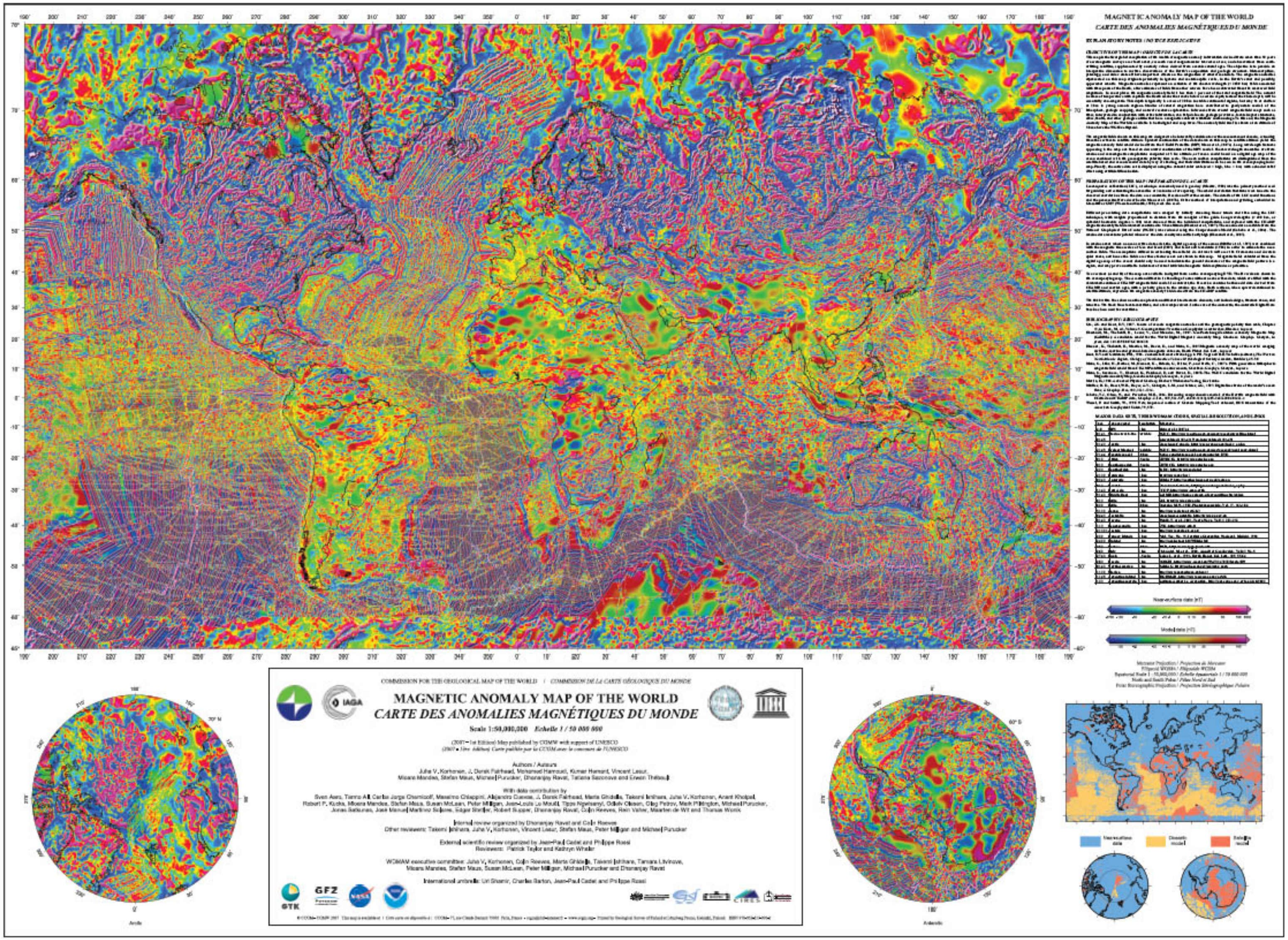
With best wishes for a successful meeting at Prague

Frank

3. Report on:
World Digital Magnetic Anomaly Map version 2.0

Jérôme Dyment (chair, WDMAM Task Force, IPGP-CNRS, France; jdy@ipgp.fr)
Manuel Catalan (co-chair; ROA, Spain)

WDMAM version 1 (Korhonen et al., 2007)



Why a WDMAM version 2?

- Many gaps in WDMAM v.1

→ need to gather more data

- A major issue : the oceans

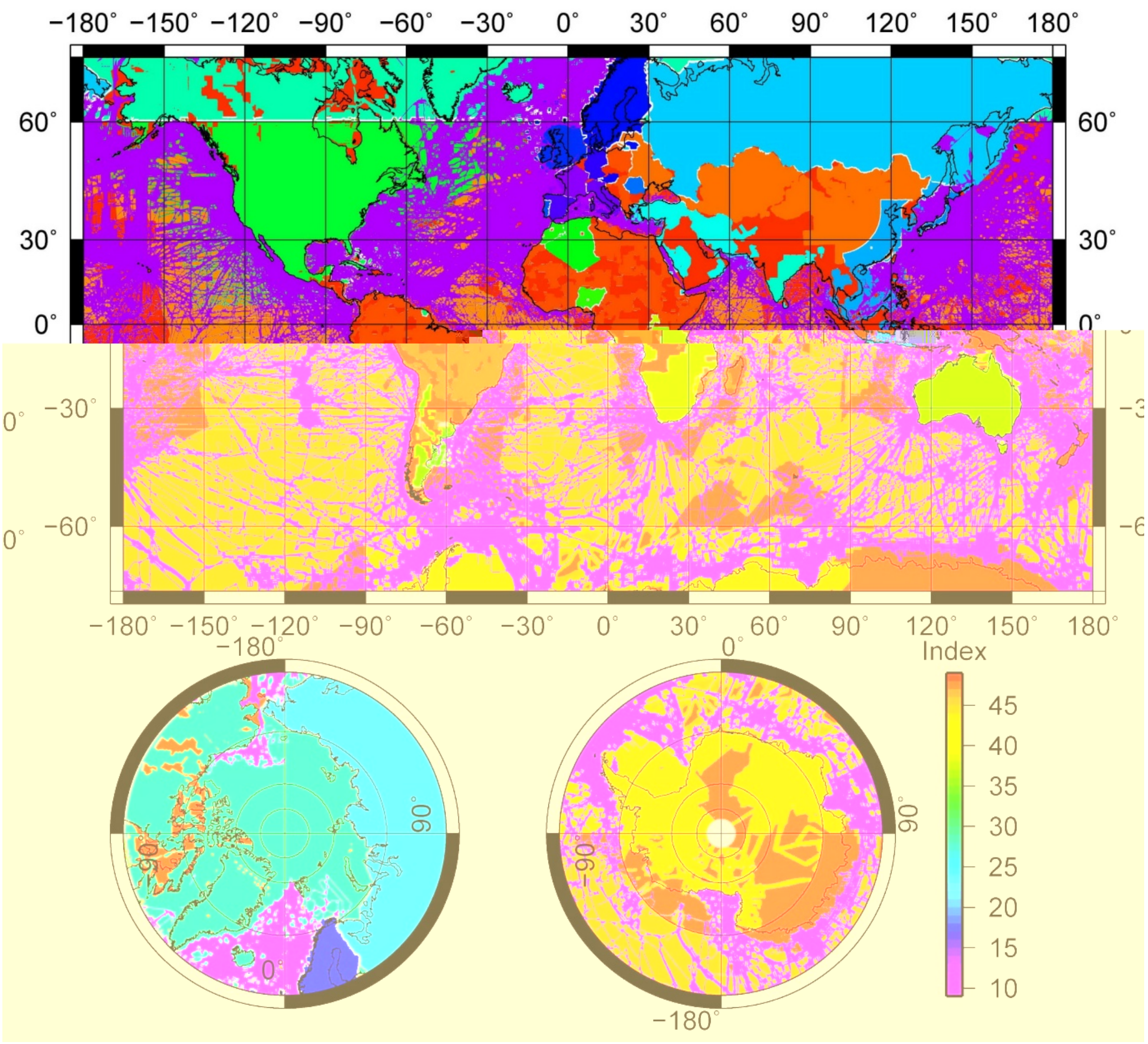
→ need to improve approach

➔ 3 applicants in 2010, 1 map delivered in 2013

Gamma (V. Lesur, GFZ, Potsdam) MarMag-Fr (J. Dyment, IPGP-CNRS, Paris)	Teams merged 2012, Map delivered 2013
GTK Team (J. Korhonen, GTK, Helsinki)	Map not delivered

➔ Evaluation process, corrections…

WDMAM v. 2.0



Sources:

- Existing compilations (North America, Russia, Australia, Antarctica, Europe, Austral Africa, Caribbean…)

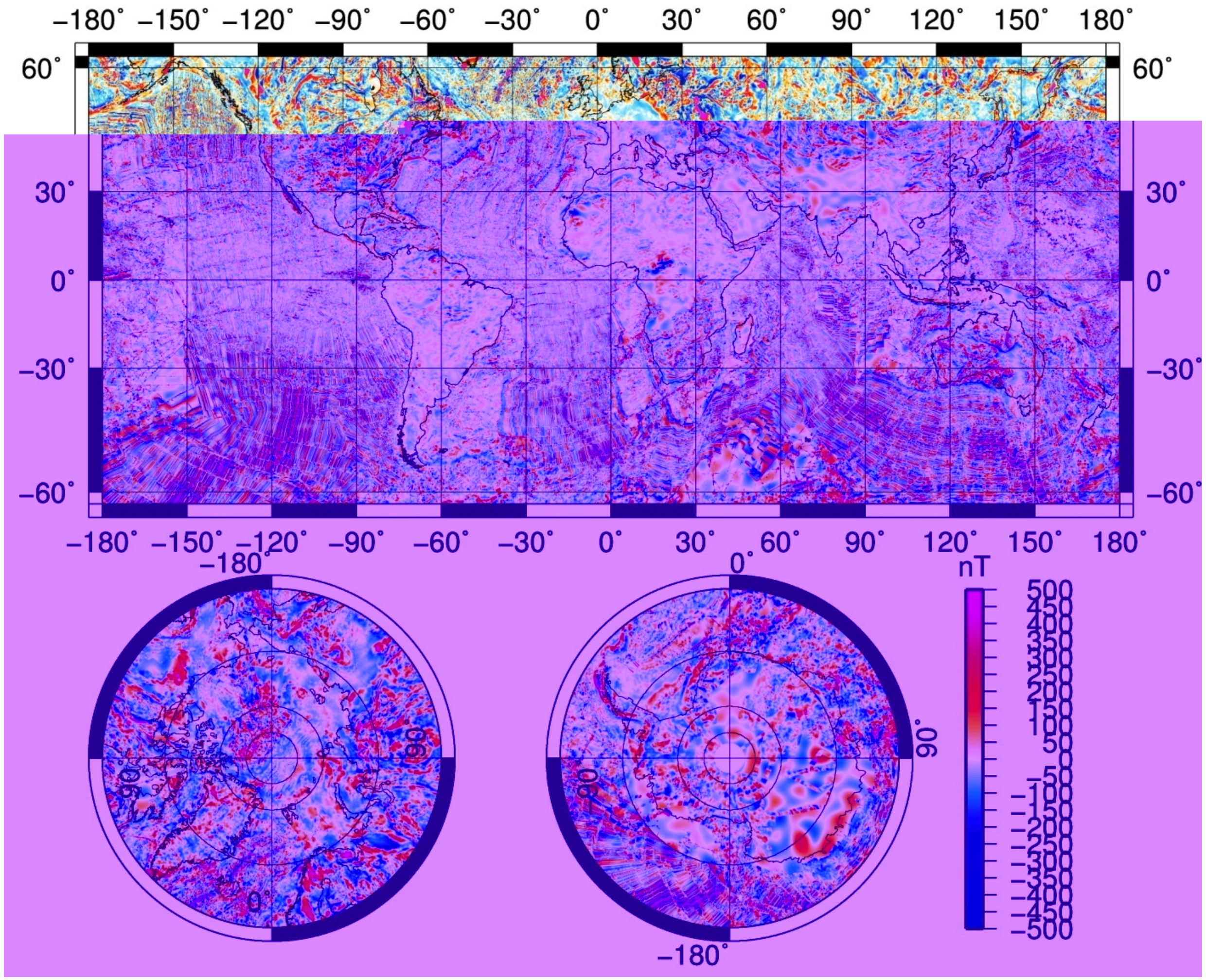
- Data provided by countries (Algeria, Nigeria…

- Low-res data compiled in EMAG-2 (high-res is proprietary)

- At sea: marine data, adjusted model except CQZ and plateaus

- elsewhere: downward-continued satellite map

WDMAM v. 2.0



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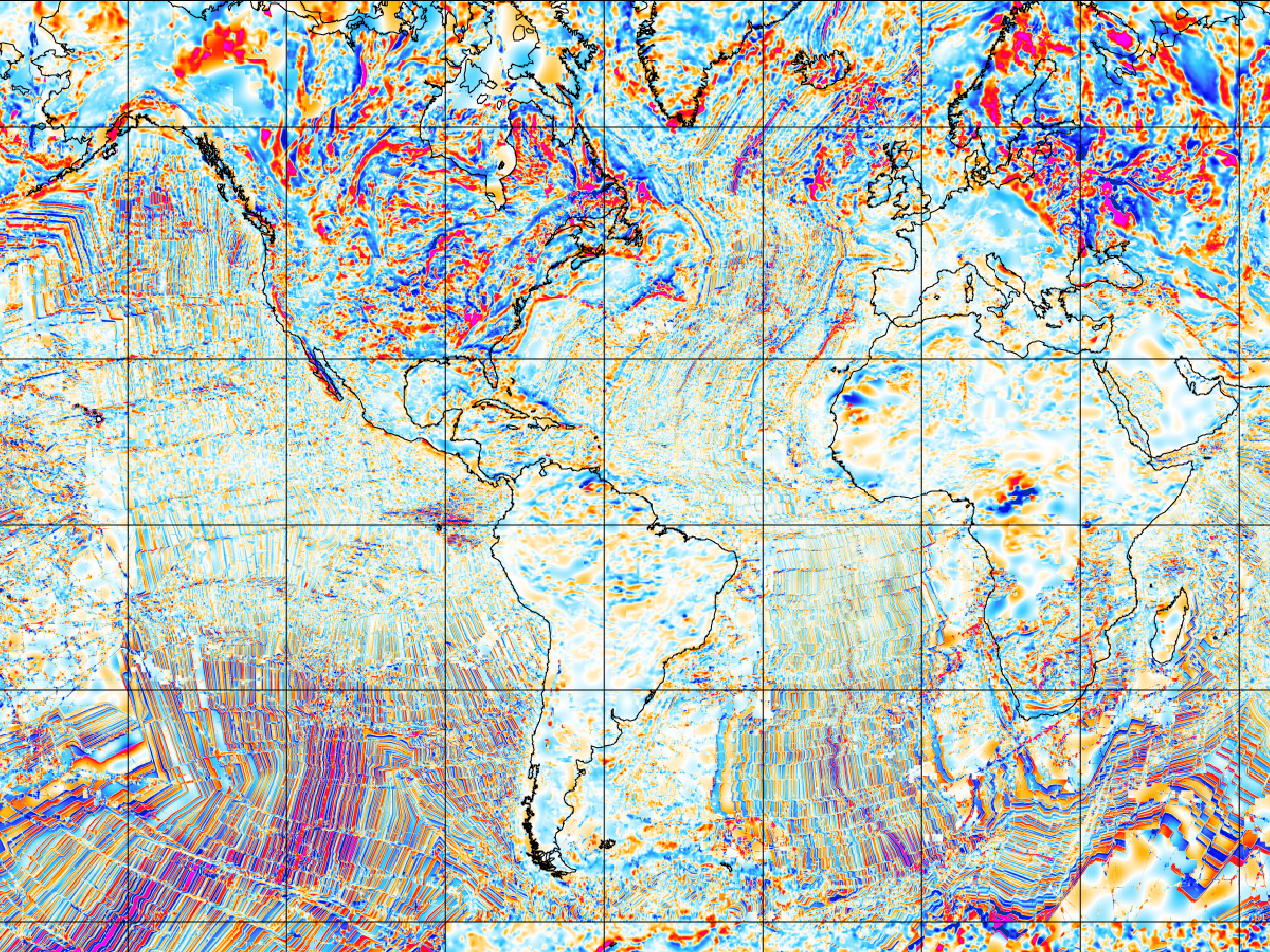
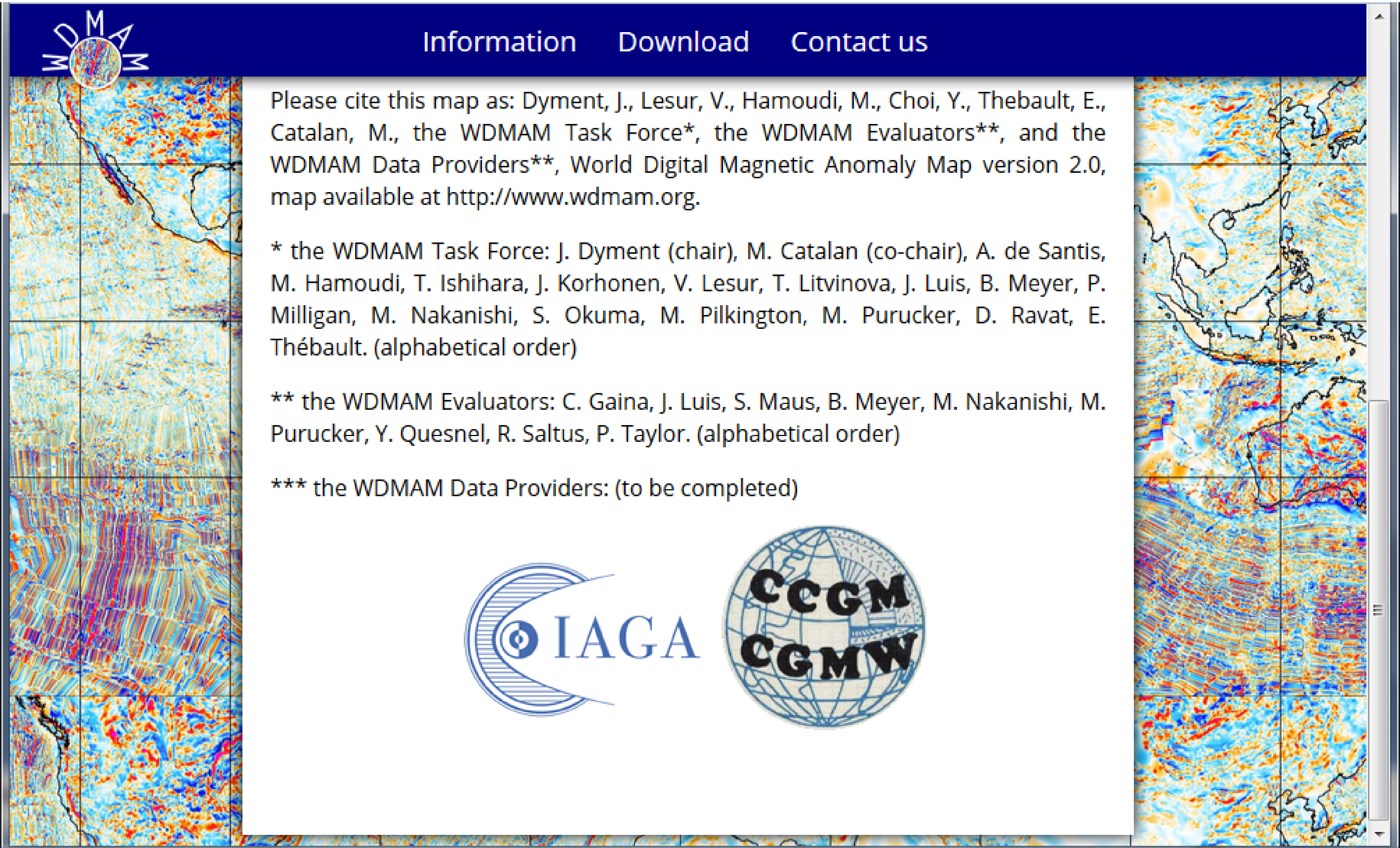


Present status and projects

- Candidate GMJC evaluated, corrections done. Adoption as WDMAM 2.0 and **release now**, publication and distribution of printed version soon.
- Proposition to improve it gradually, as new data are coming, through versions 2.1, 2.2… Start the whole process (call, evaluation) in 2 years for WDMAM 3.0.
- Search for more data in academic, geological surveys and industry. Any help very appreciated!
- Collection of data in remote oceanic areas through a project involving oceanographic institutions, magnetometer builders and educational aspects.

wdmam.org



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* the WDMAM Task Force: J. Dyment (chair), M. Catalan (co-chair), A. de Santis, M. Hamoudi, T. Ishihara, J. Korhonen, V. Lesur, T. Litvinova, J. Luis, B. Meyer, P. Milligan, M. Nakanishi, S. Okuma, M. Pilkington, M. Purucker, D. Ravat, E. Thébault. (alphabetical order)

** the WDMAM Evaluators: C. Gaina, J. Luis, S. Maus, B. Meyer, M. Nakanishi, M. Purucker, Y. Quesnel, R. Saltus, P. Taylor. (alphabetical order)

*** the WDMAM Data Providers: (to be completed)

IAGA CCGM CGMW

4. Election of new co-chair

- C. Finlay stepping down after IUGG
- Propose E. Thebault will continue, moving from co-chair to chair
- Need new co-chair of V-MOD
- Candidate: Patrick Alken (US)

5. Proposed sessions for IAGA 2017:

1. Results from *Swarm* and preceding satellite missions
   Conveners: Claudia Stolle, Patrick Alken, Ciaran Beggan
   (Inter-Commission. Joint with other divisions)

2. Lithospheric field, WDMAM, and geological/tectonic interpretations
   Conveners: Erwan Thebault, Foteini Vervelidou, Stavros Kotsiaros

3. Secular Variation: Studies from ground and satellite data and modelling core dynamics
   Conveners: Vincent Lesur, Nicolas Gillet
   (Joint with WG V-OBS, DIV I)

6. Any other business?