Global Geomagnetic Field Models from DMSP Satellite Magnetic Measurements

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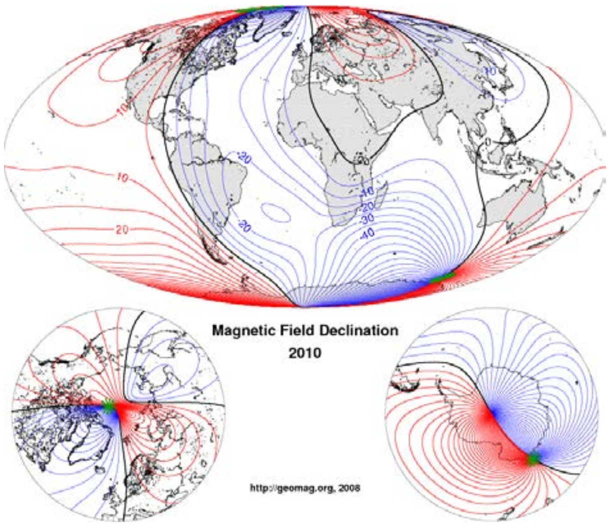
Outline

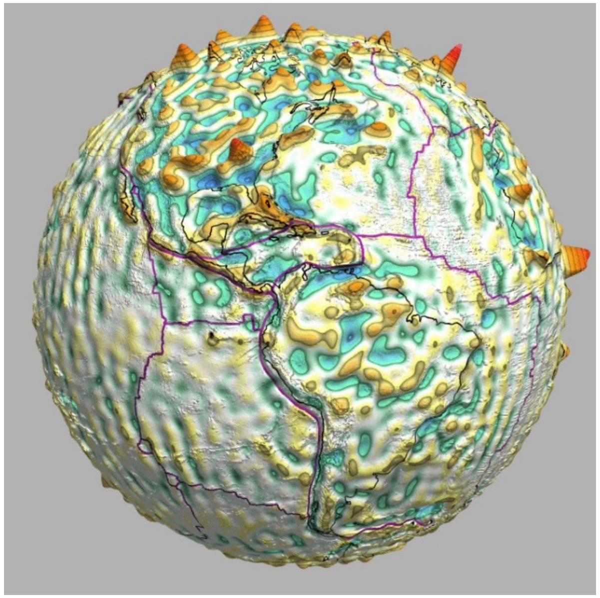
- Background
- Satellite missions for geomagnetic modeling
- DMSP data calibration
- DMSP model validation
- High Definition Geomagnetic Model (HDGM)

Background of geomagnetic field

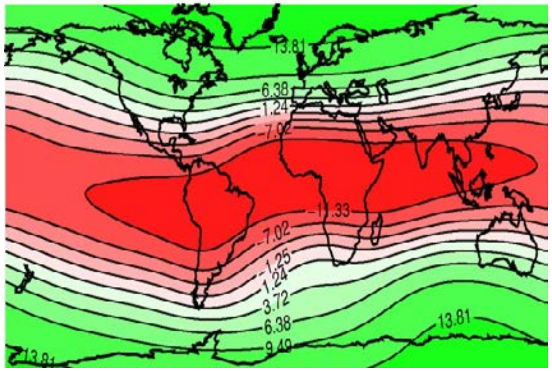
Main field



Crustal field

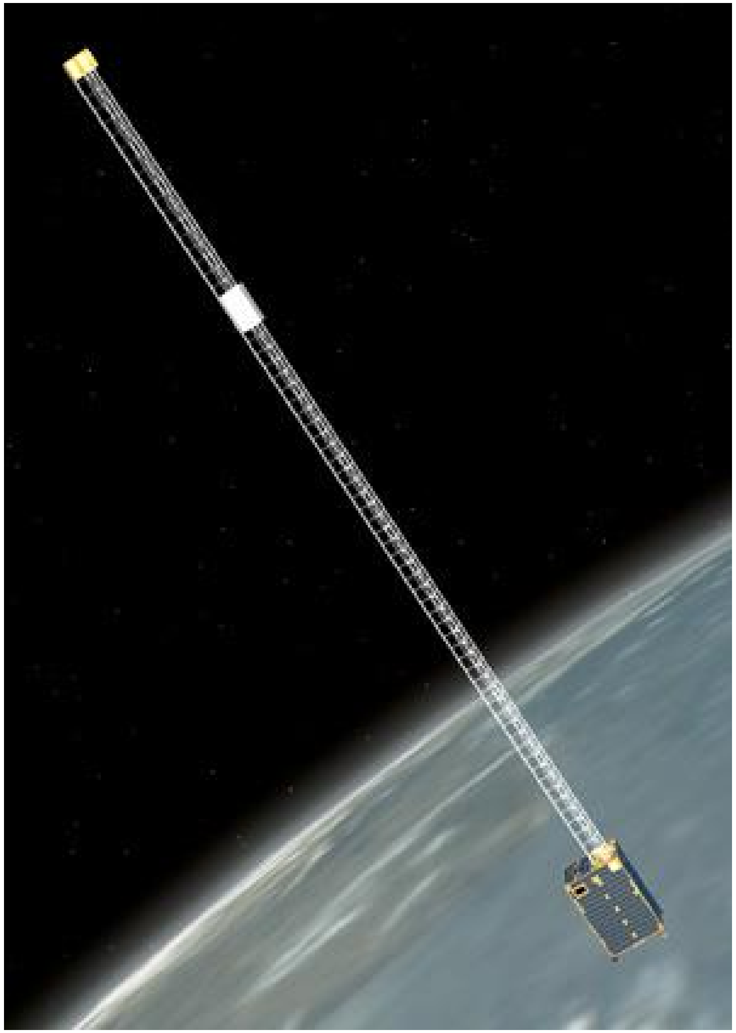


Disturbance field

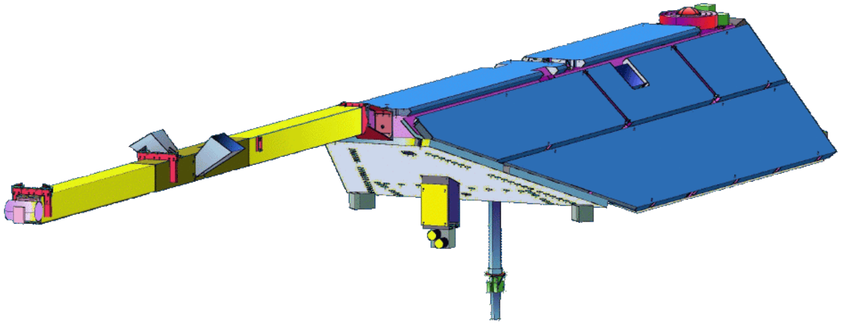


Ørsted mission

- February 1999 - present
- 640-850 km altitude
- Inclination: 96.5°
- Provides only scalar data since 2005 due to star camera failure



CHAMP mission



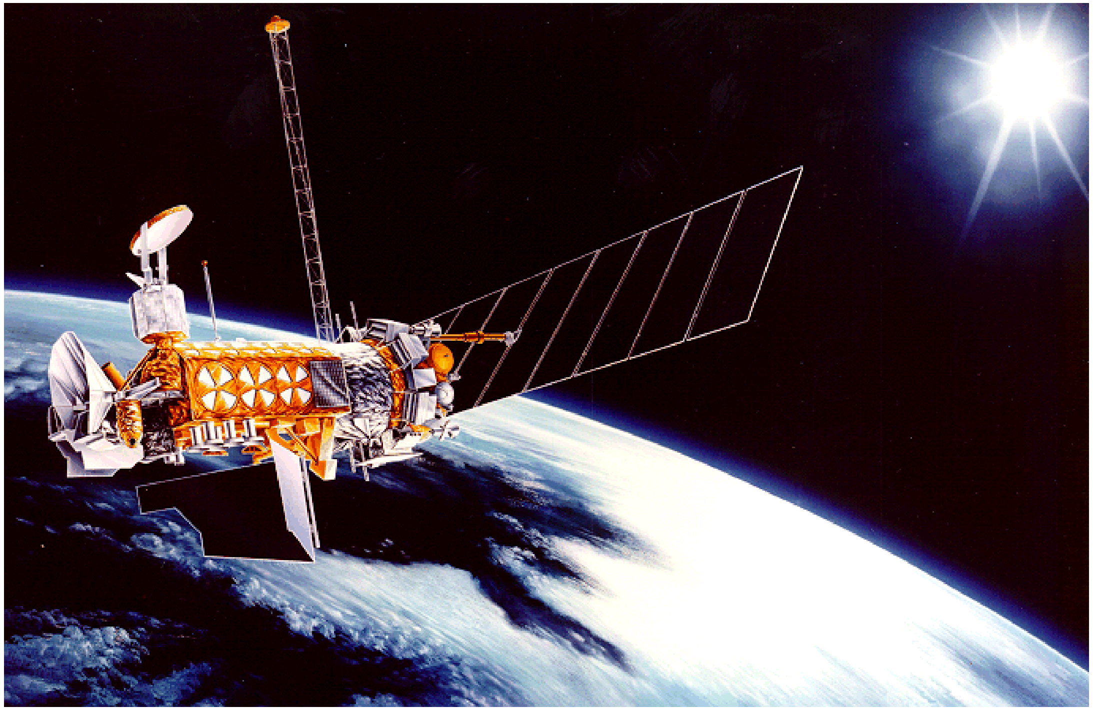
- July 2000 – September 2010
- 450 km initial altitude
- Drifts rapidly in local time
- Inclination: 87.3°
- Scalar and vector magnetometers
- 2-head star camera

Swarm mission

- Successful launch in November 2013
- 3-satellite constellation (A,B,C)
- Inclination:
  - A/B: 87.4°
  - C: 88°
- Period: 90 minutes
- Altitude:
  - A/C: 460km
  - B: 510km
- 3-head star camera
- Scalar and vector magnetometers

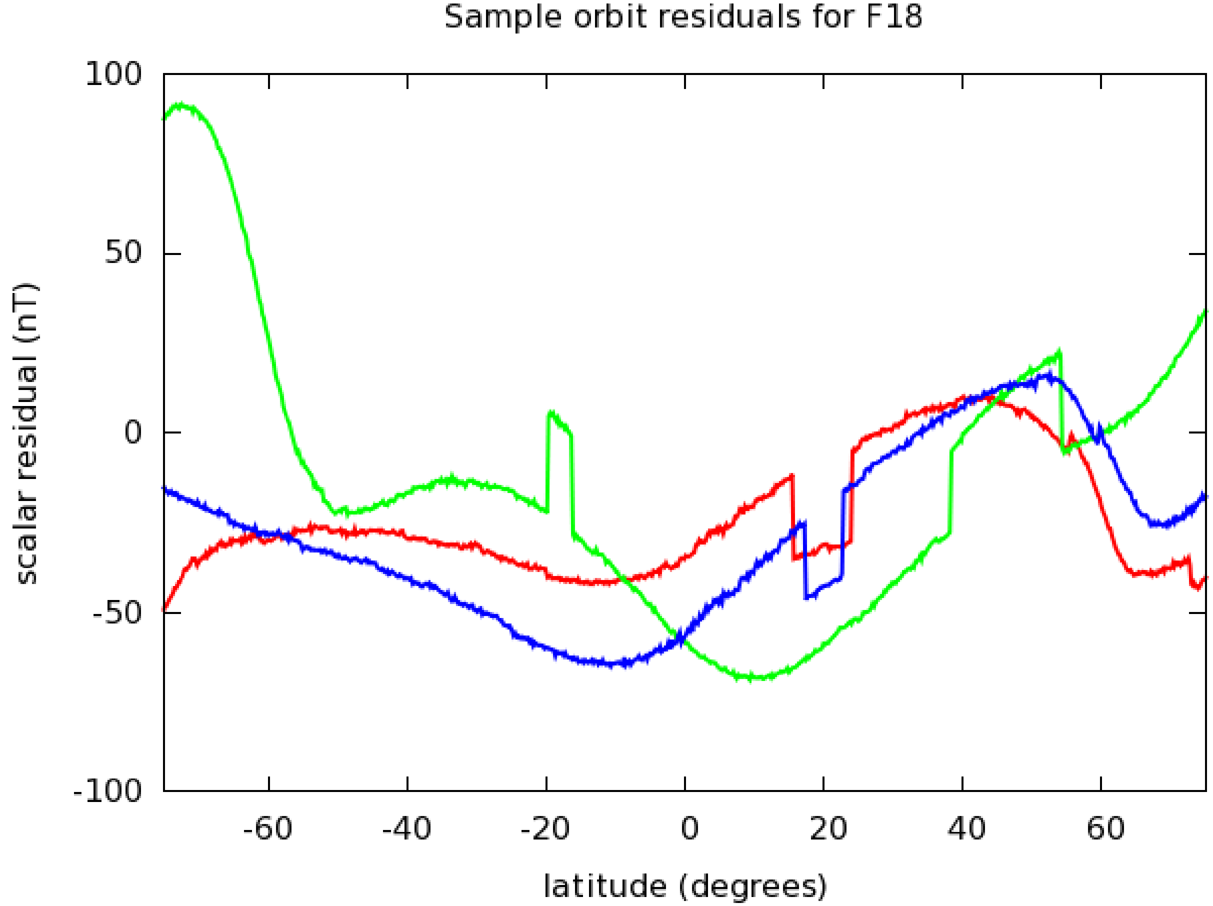
DMSP mission

- 5 satellites with boom mounted magnetometers: F15-F19
- Circular, sun synchronous orbits
  - F15: 6am/6pm
  - F16: 8am/8pm
  - F17: 5:30am/5:30pm
  - F18: 8am/8pm
  - F19: 8:30am/8:30pm
- Inclination: 98.8°
- Period: 102 minutes
- Altitude: 850 km
- Vector magnetometer only
- Operational mission: magnetic measurements are not research quality



DMSP data: residuals along orbit

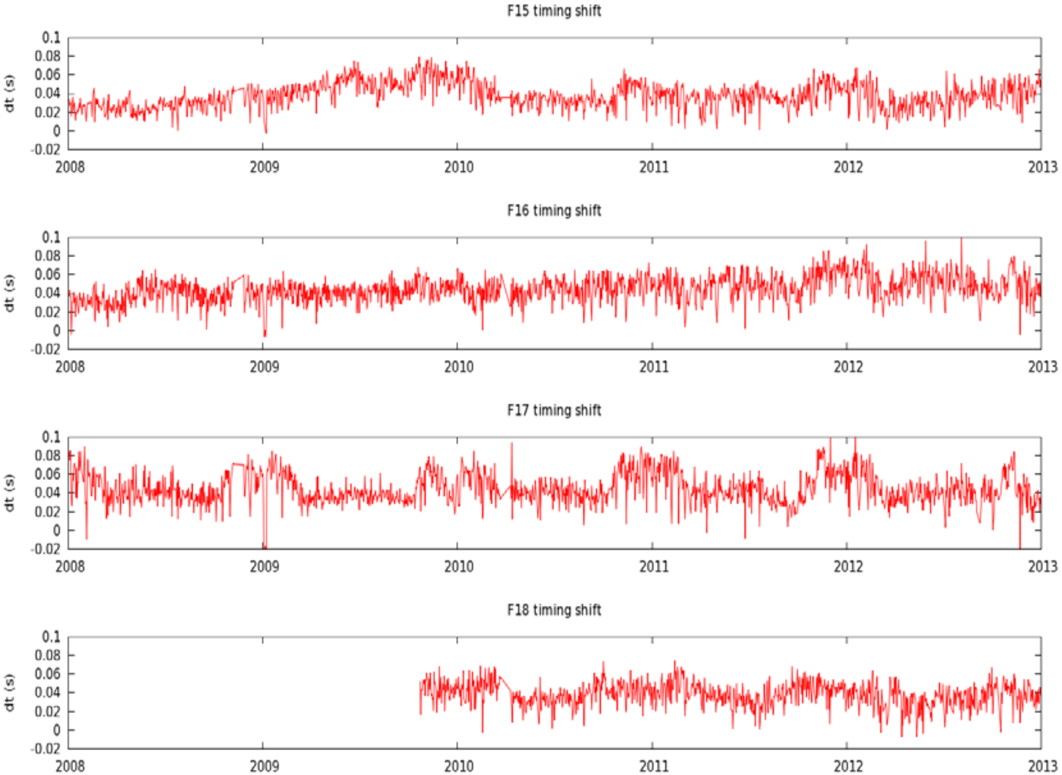
- Nearly every orbit of DMSP contains data jumps as shown in the figure
- Jumps could be due to various instruments turning on/off (heaters, solar panels, torquers,etc)
- Jumps could be artifacts from previous calibrations from ground station
- These jumps must be carefully removed as they significantly affect the calibration



Calibration: Timing shift

$$\epsilon(\delta t) = \sum_i \left[F_i - F^{main}(\mathbf{r}(t_i + \delta t))\right]^2$$

- Time delay between when a measurement is made and when it is timestamped and recorded
- Very important for fast-moving satellites, as the field can change by several nT

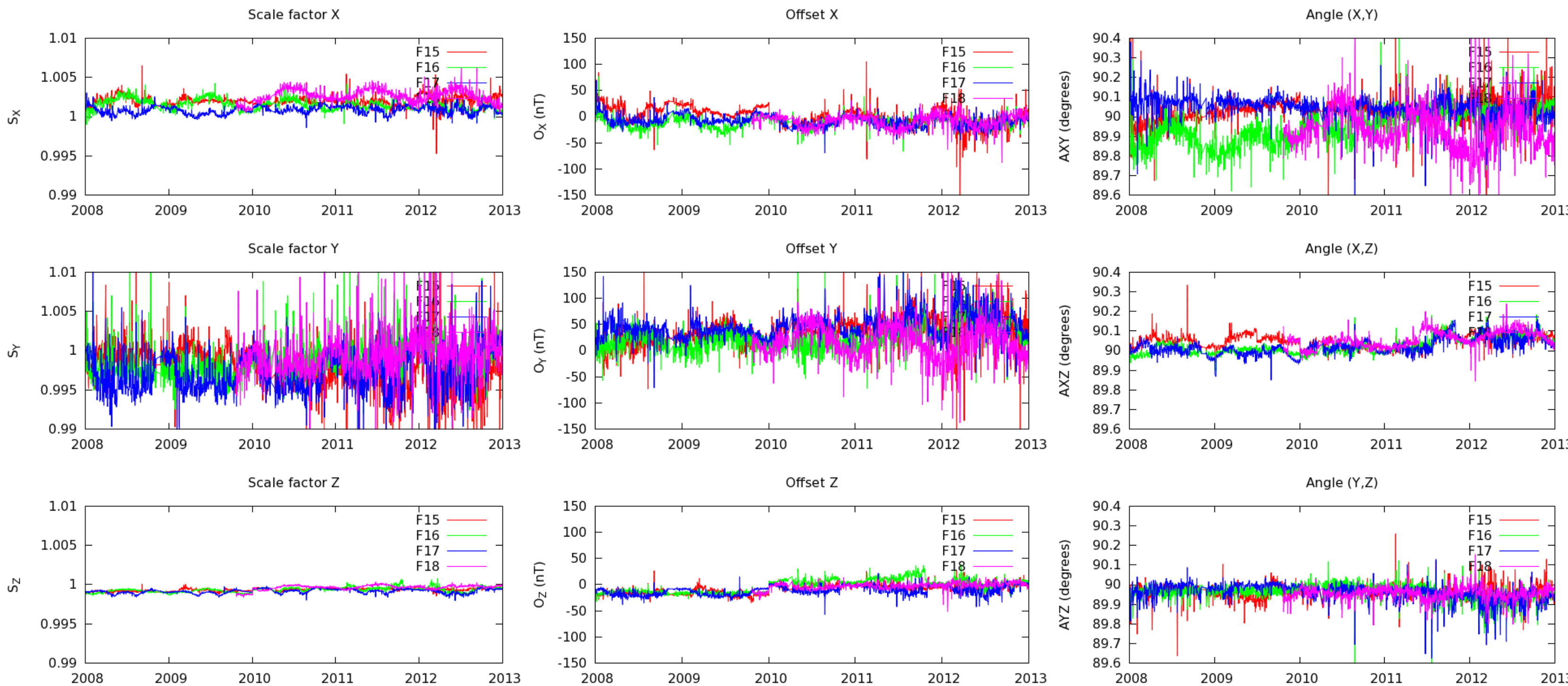


Scalar Calibration

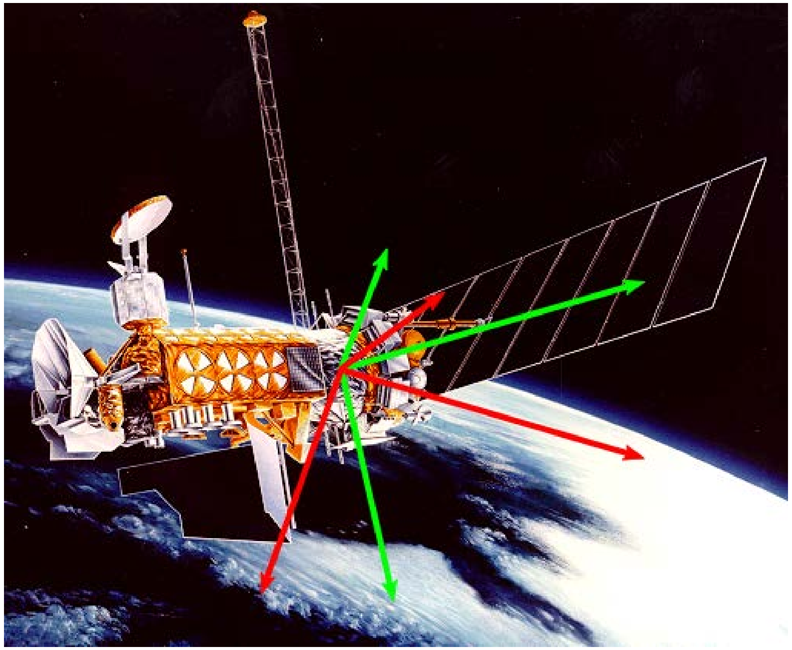
- Scale factors: S_x, S_y, S_z
- Offsets: O_x, O_y, O_z
- Non-orthogonality angles: α_{xy}, α_{xz}, α_{yz}

$$\mathbf{B} = \begin{pmatrix} S_x & \cos\alpha_{xy} & \cos\alpha_{xz} \\ 0 & S_y & \cos\alpha_{yz} \\ 0 & 0 & S_z \end{pmatrix} \mathbf{E} + \begin{pmatrix} O_x \\ O_y \\ O_z \end{pmatrix}$$

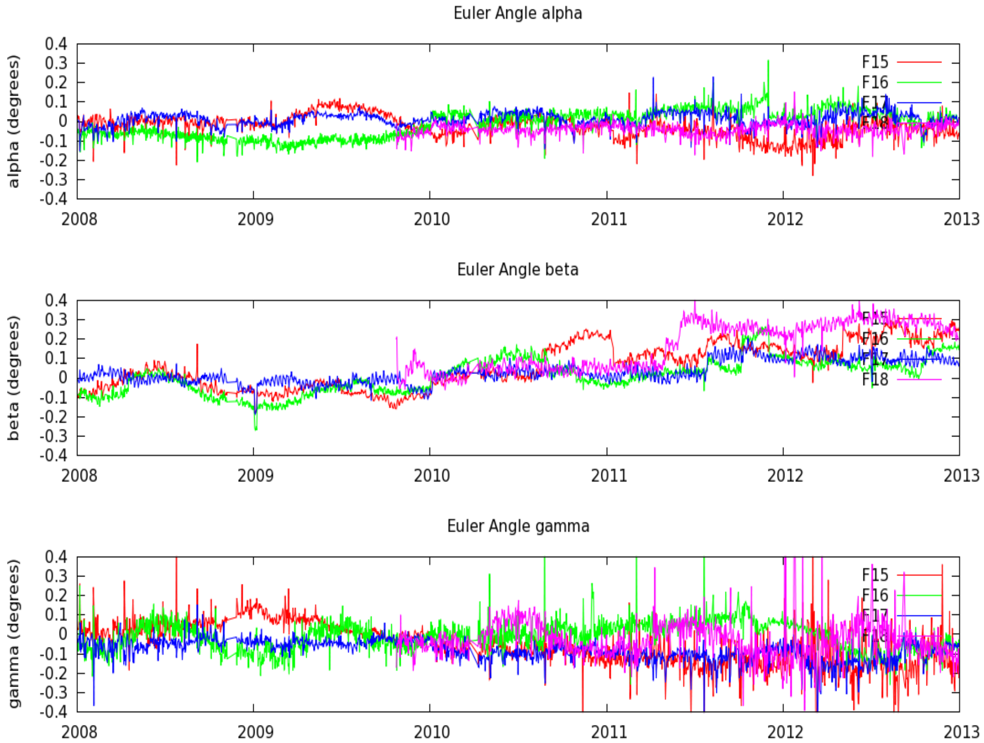
$$\epsilon(\mathbf{S}, \mathbf{O}, \boldsymbol{\alpha}) = \sum_i \left[|\mathbf{B}(\mathbf{E}_i; \mathbf{S}, \mathbf{O}, \boldsymbol{\alpha})| - F^{main}(\mathbf{r}(t_i + \delta t)) \right]^2$$



Euler Angles



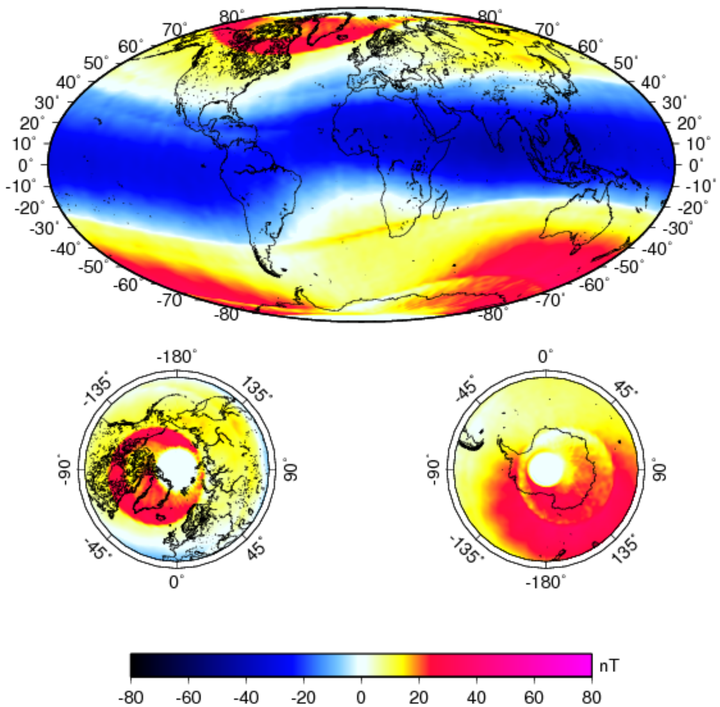
$$\mathbf{B}^{geocentric} = TR_x(\alpha)R_y(\beta)R_z(\gamma)\mathbf{B}^{magnetometer}$$



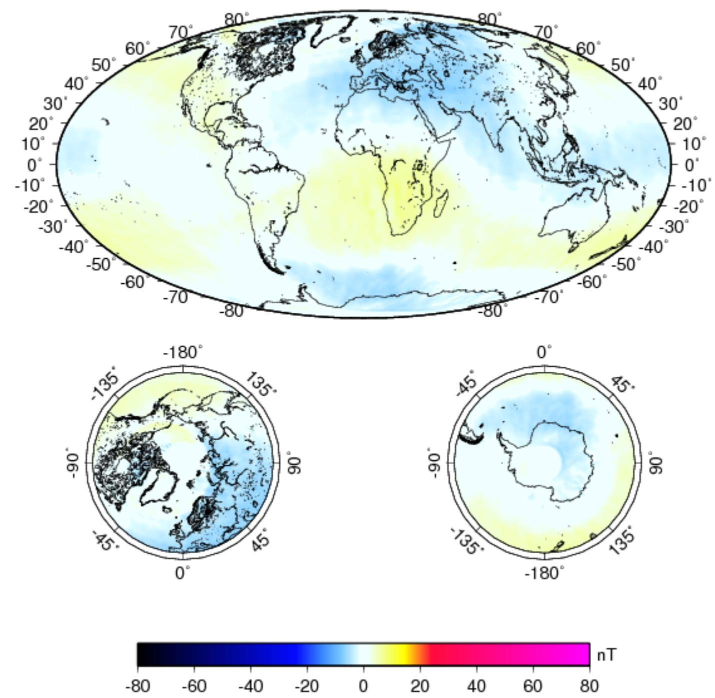
Transform measurement vector from instrument frame to satellite frame (and then to geocentric frame)

Calibrated DMSP residuals

F16 2010 original residuals



F16 2010 calibrated residuals

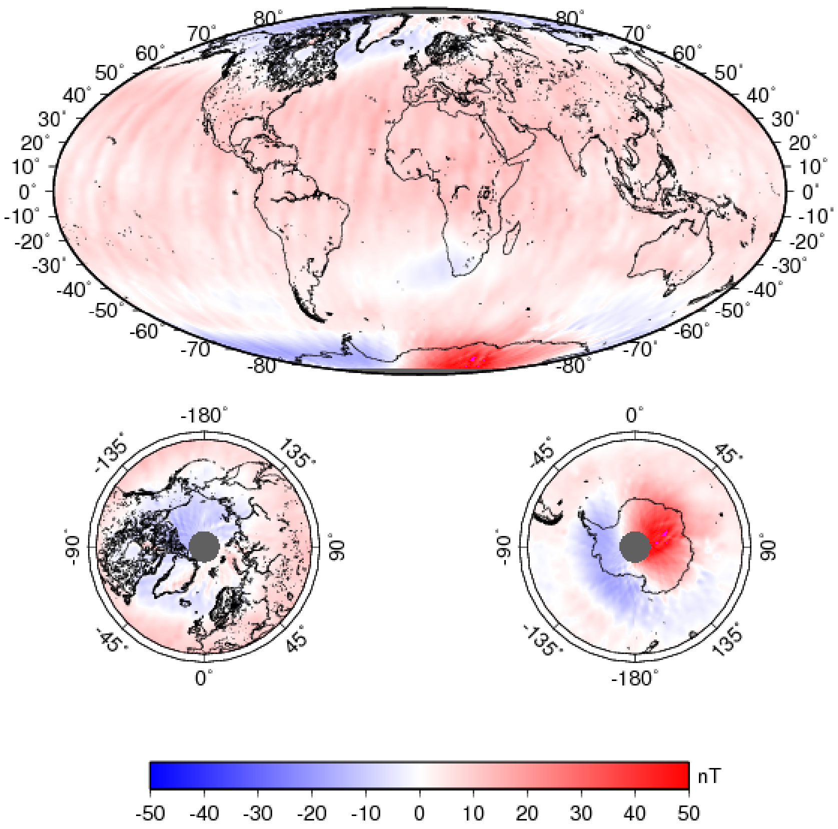


DMSP Main Field Modeling

- degree 15 spherical harmonic model for main field
- Data selection criteria
  - Data period: January 2009 through December 2013
  - Night time data (between 1800 and 0600 LT)
  - Selected times with low Dst and Kp indices, to minimize the influence of external fields

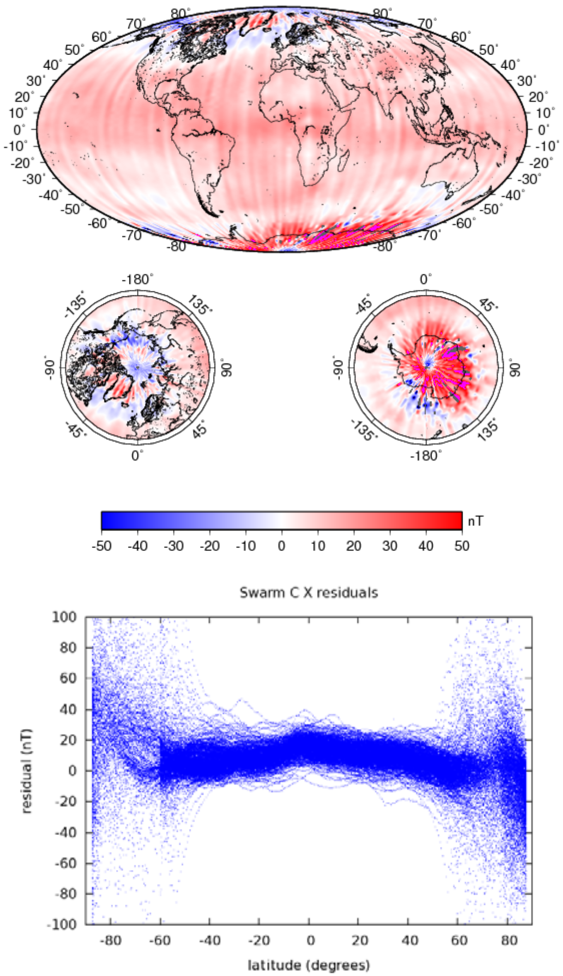
DMSP validation with Ørsted

- Ørsted scalar data from January 2013 to June 2013
- Subtracted DMSP main field model with external field from Ørsted data
- RMS difference = 12.1 nT over the globe



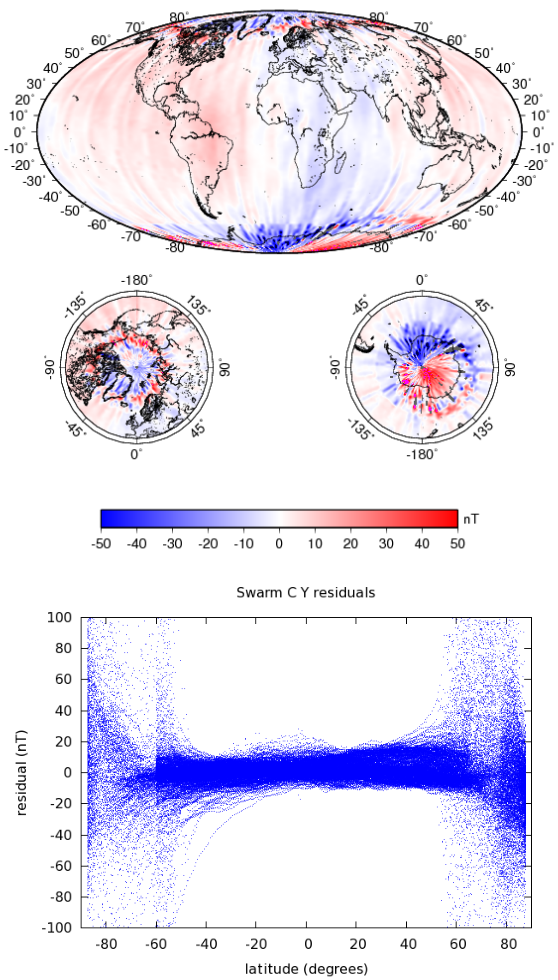
DMSP validation with Swarm C

North



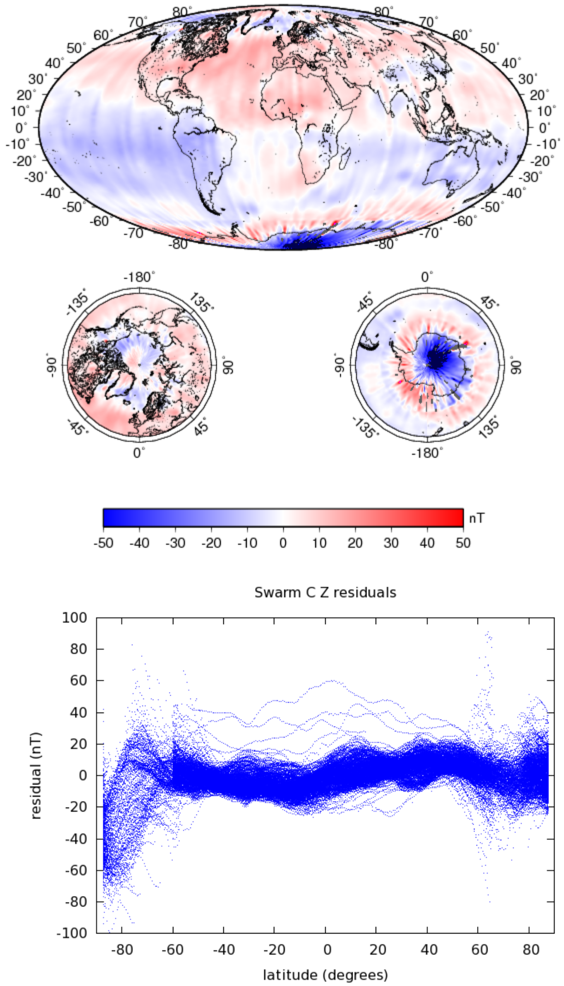
Rms = 11.3 nT

East



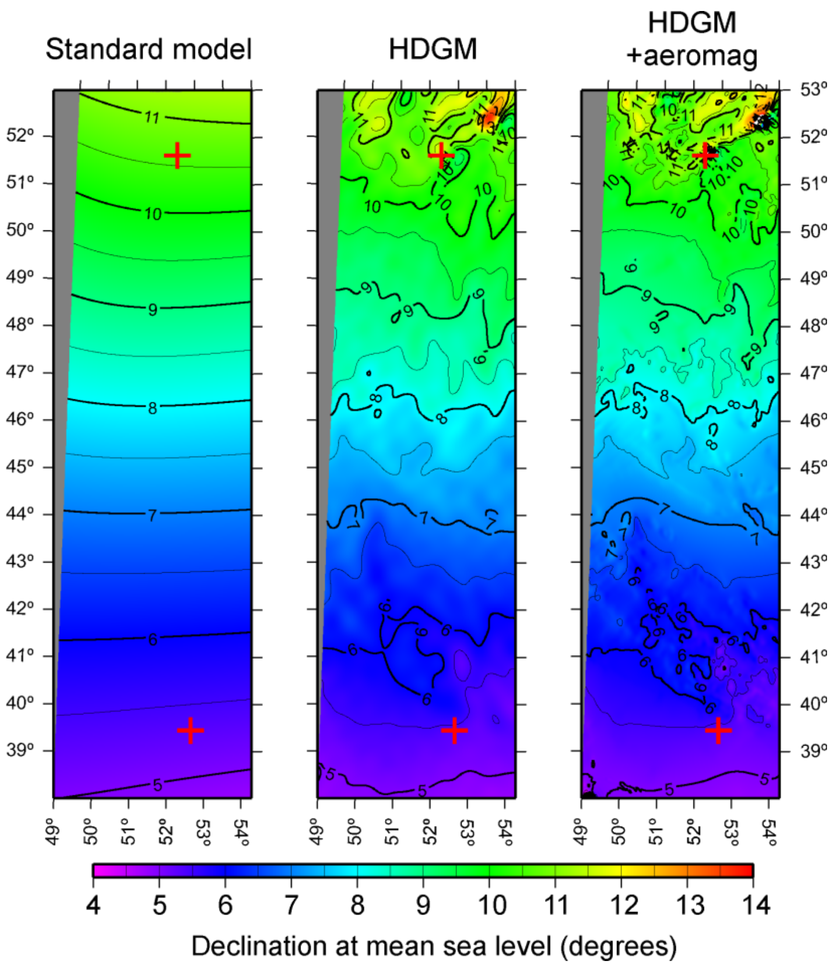
Rms = 8.5 nT

Vertical



Rms = 8.3 nT

High Definition Geomagnetic Model



- Main field
- Secular variation
- Crustal field to degree 720
- Basic model for external field
- Error estimates using ISCWSA error model

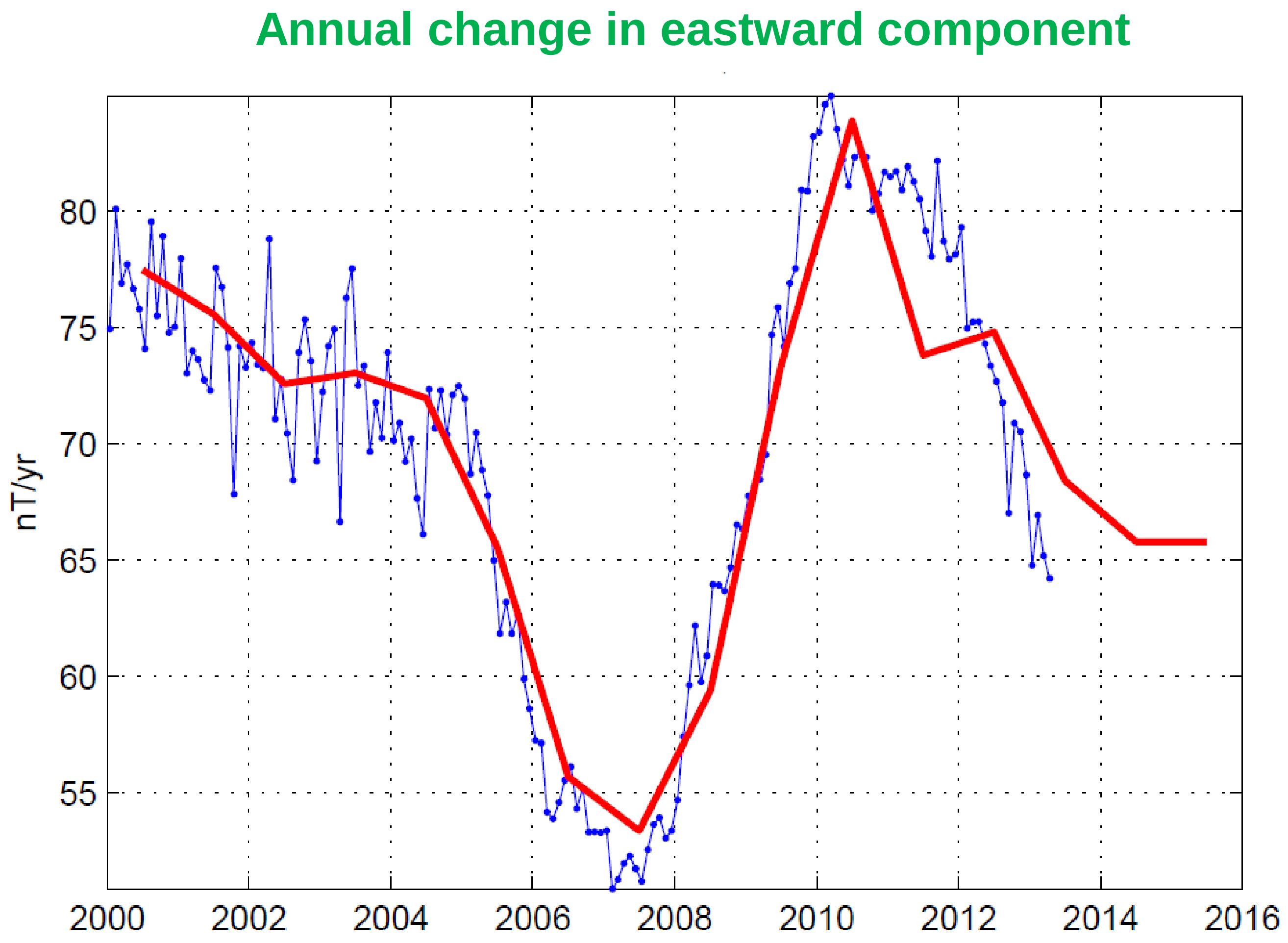
Datasets used:

- CHAMP (2000-2010)
- DMSP (2011-2015)
- Aeromag surveys
- Marine surveys
- IGRF (1980-1999)

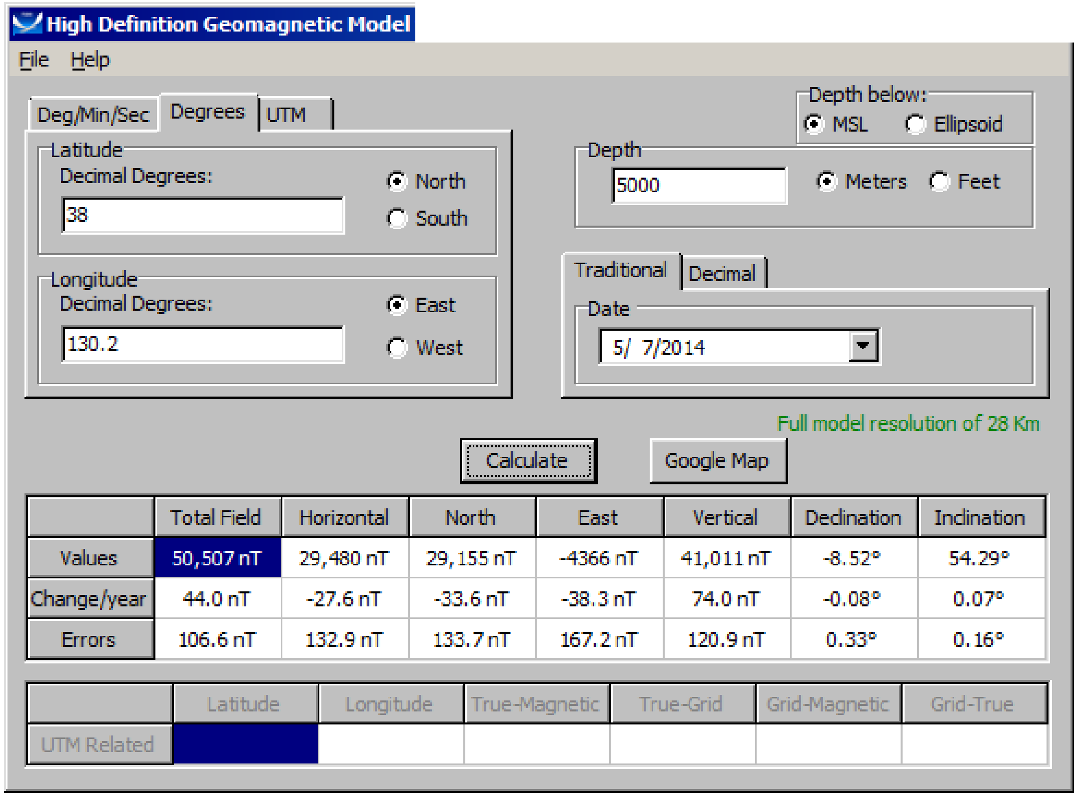
Model updated annually
http://www.ngdc.noaa.gov/geomag/hdgm.shtml

HDGM comparison with ground observatories

- Secular variation comparison with MBO observatory in Senegal
- Years 2000-2010 based on CHAMP, aeromag, marine data
- Years 2011-2015 based on DMSP, aeromag, marine data
- Very important to update the HDGM yearly due to sudden changes in secular variation

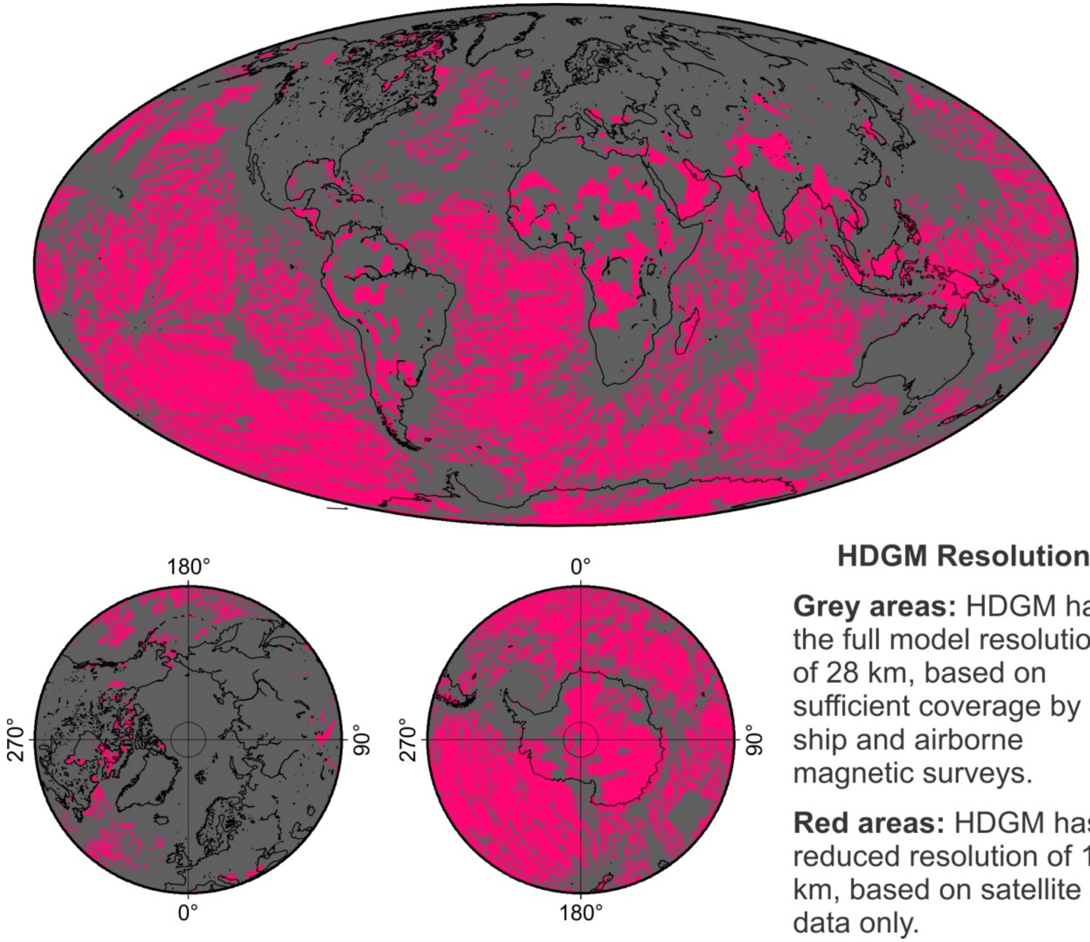


HDGM Software



- Provides field values, secular variation and error estimates for a given location and time
- We also provide a console program and excel interface to perform batch calculations of field values
- 1σ error estimates from ISCWSA error model

HDGM resolution mask



HDGM Resolution

Grey areas: HDGM has the full model resolution of 28 km, based on sufficient coverage by ship and airborne magnetic surveys.

Red areas: HDGM has a reduced resolution of 130 km, based on satellite data only.

Error estimates take into account full/reduced resolution regions

Conclusions

- DMSP dataset has been calibrated for geomagnetic field modeling
- DMSP-based models have been validated with independent data from Ørsted, Swarm, and ground observatories
- HDGM2014 has been released and validated
  - New coverage extending back to 1980 and forward to end of 2015
  - Years 2011-2015 updated with more accurate models from DMSP
  - New field error estimates provided using ISCWSA error model
- More information about HDGM: http://www.ngdc.noaa.gov/geomag/hdgm.shtml