Recent Advances in Crustal and Disturbance Field Modeling

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Speaker Information

- Arnaud Chulliat
- New Capabilities of NOAA's High-Resolution Geomagnetic Reference Models
- October 12, 2017
- University of Colorado Boulder & NOAA National Centers for Environmental Information (NCEI)

ISCWSA

Speaker Bio

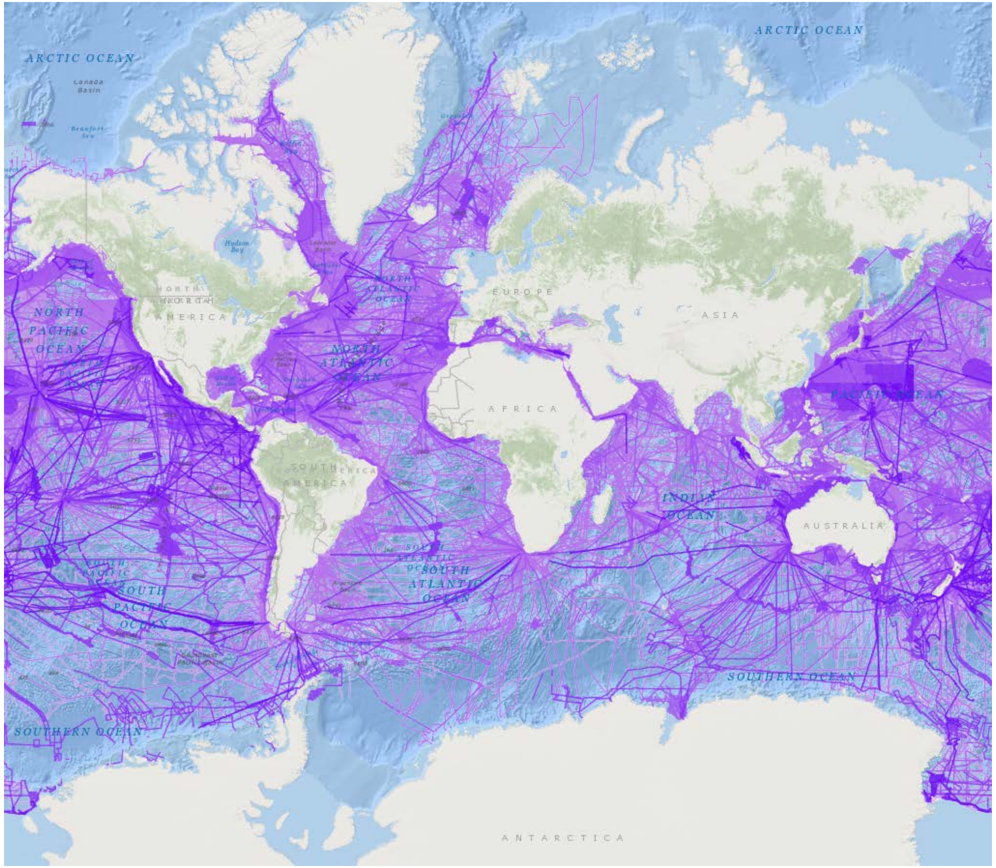
- Research Scientist, University of Colorado Boulder
- NOAA NCEI Geomagnetism Team Lead
- PhD Geophysics (Institut de Physique du Globe Paris, 2000)
- Director of the French Geomagnetic Network until 2014
- Based in Boulder, Colorado
- Specialized in Geomagnetic Field Modeling, Data Analysis & Observation Techniques

Company / Affiliation Information

- CIRES/NCEI Geomagnetism develops NOAA's
  - High Definition Geomagnetic Model (HDGM)
  - High Definition Geomagnetic Model - Real Time (HDGM-RT)
- CIRES/NCEI Geomagnetism develops or co-develops
  - DoD World Magnetic Model (with BGS)
  - International Geomagnetic Reference Field (IGRF)
  - Global magnetic anomaly grids (e.g., EMAG2v3)
  - Various Swarm satellite level 2 products
  - Other research geomagnetic models

NOAA/NCEI GEOphysical Data System (GEODAS)

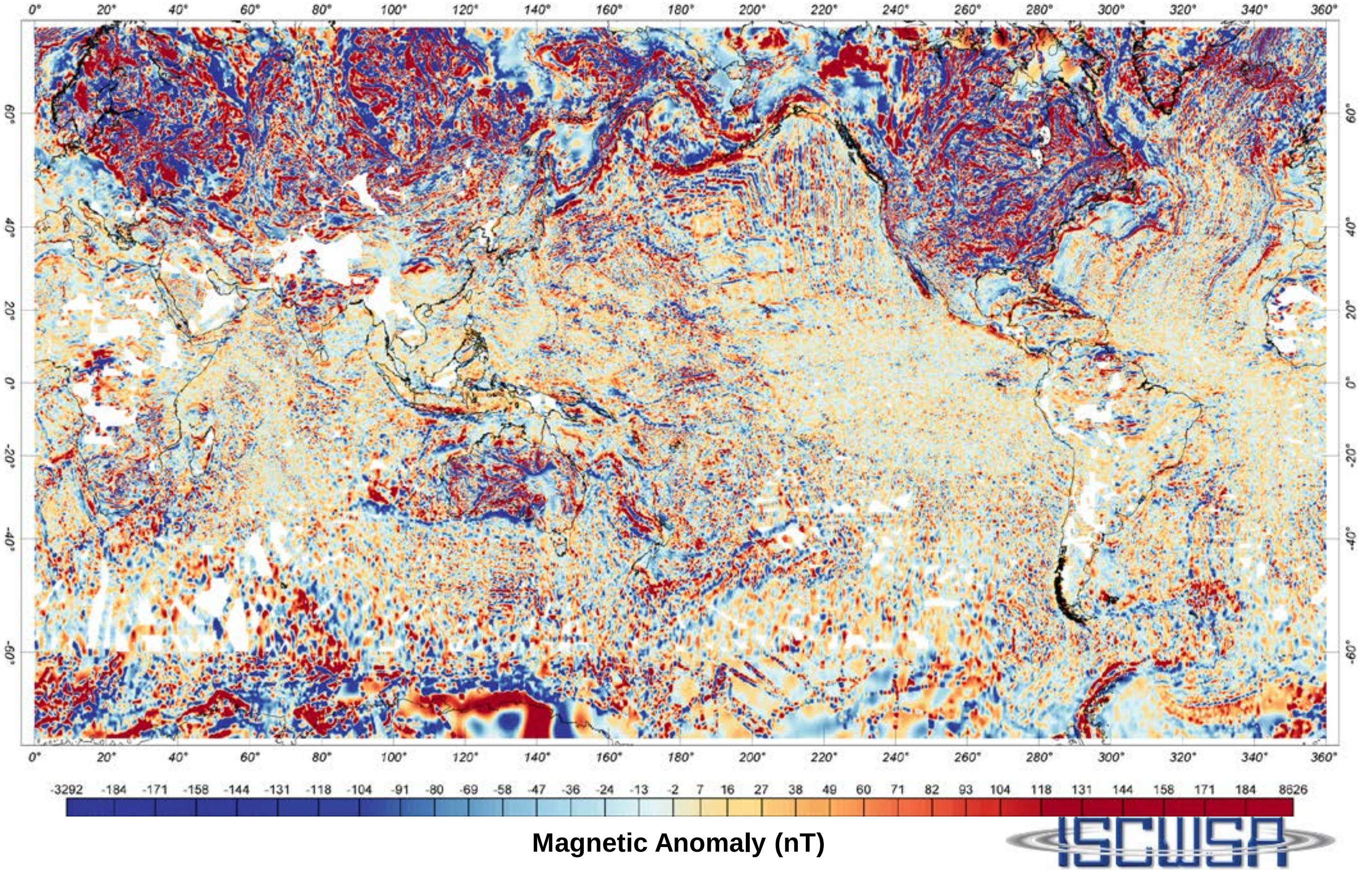
- Marine and airborne trackline data:
  - > 100 institutions
  - > 50 years
  - 3255 surveys (657 added)
  - 75.9 M data points (50.6M added)
  - 10.5 M miles (2.5 M added)
- Precompiled grids over continental areas
- Large-scale (>300 km) anomalies provided by satellite-based field model



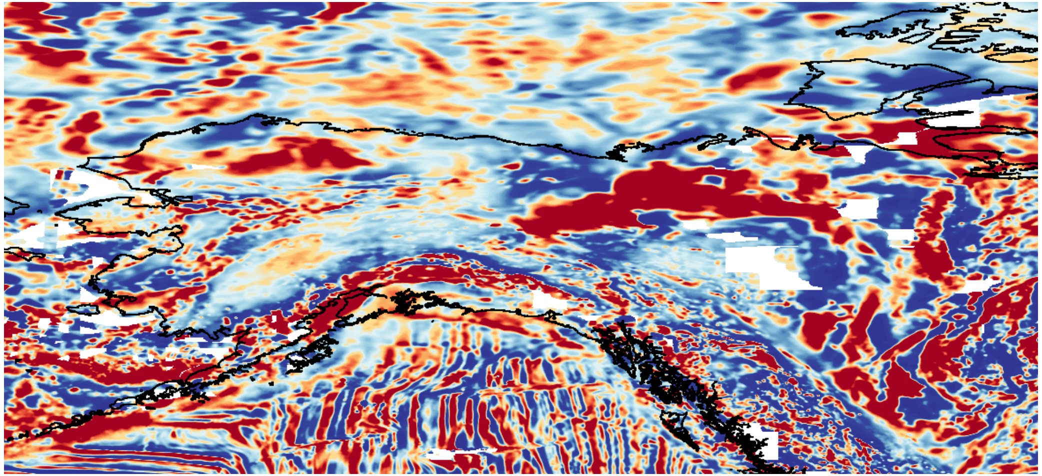
EMAG2v3

- Different and fully independent algorithm
- Use no a-priori information (e.g. on ocean age of magnetization)
- More trackline data (>50M new data in GEODAS since 2010)
- New Alaska continental grid
- Each grid cell fully traceable to the data
- doi:10.7289/V5H70CVX

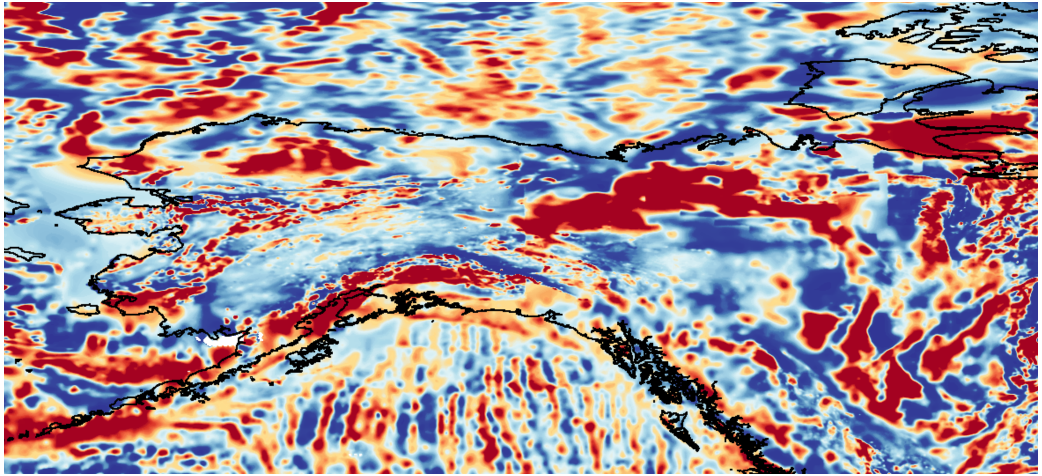
Earth Magnetic Anomaly Grid (EMAG2v3)
2 arc-minute resolution
4 km Altitude



Alaska

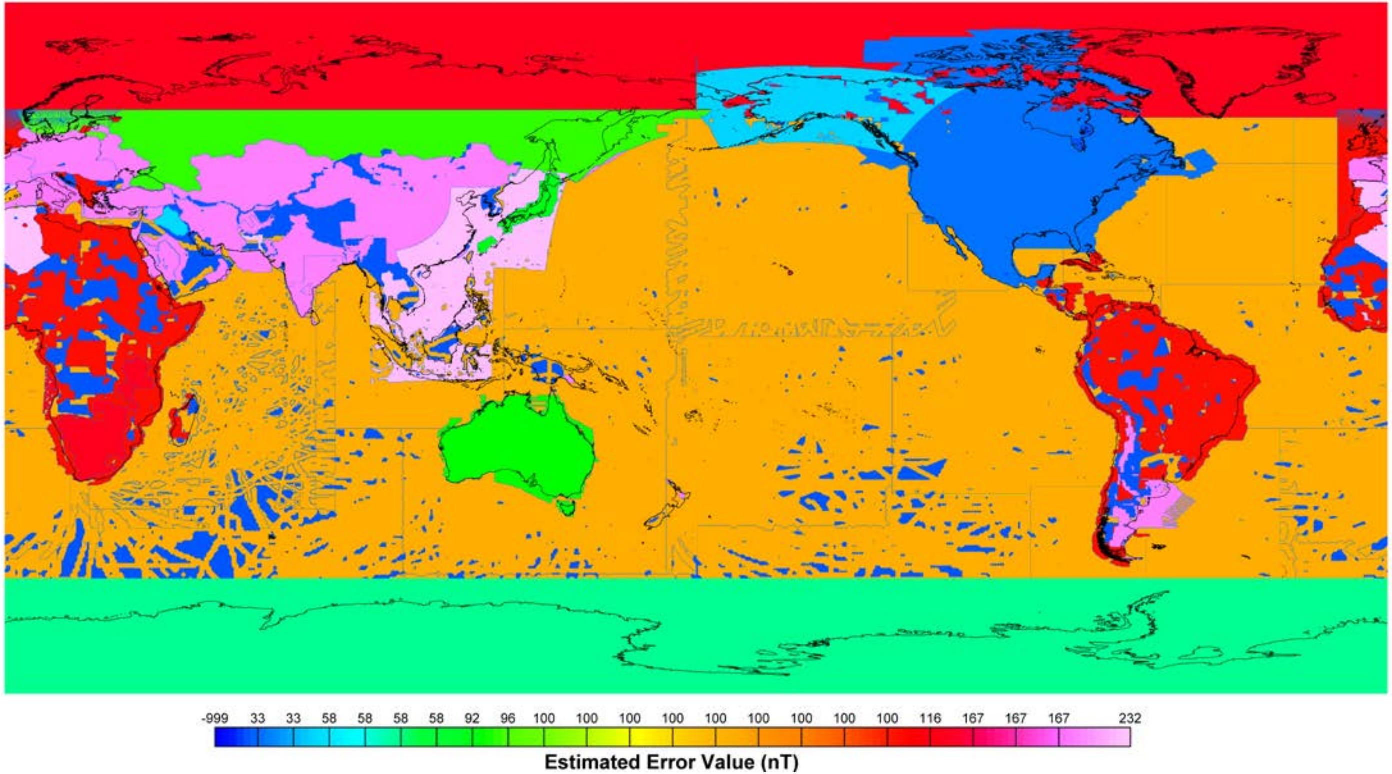


EMAG2 (2009)



EMAG2v3 (2017)

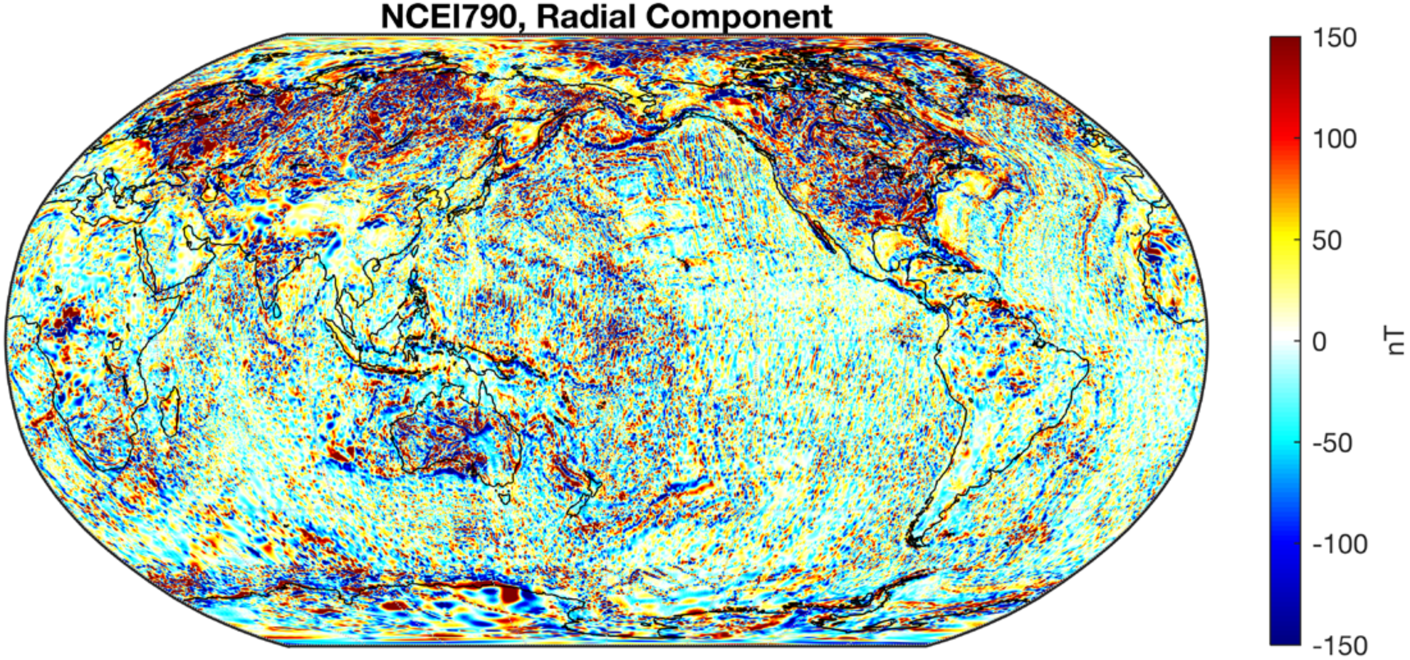
Global Map of Uncertainties



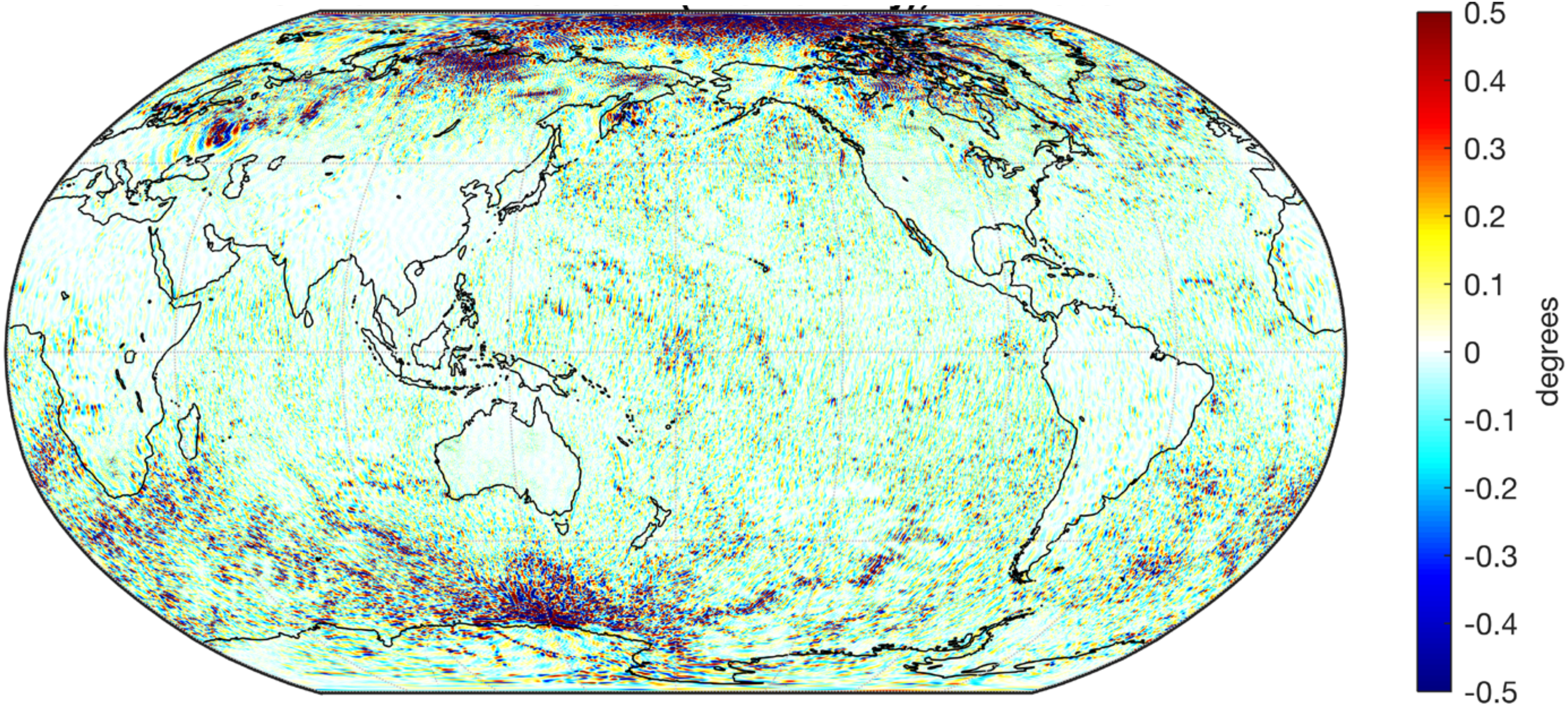
- Reflects heterogeneity in survey data quality
- 1σ error

NCEI790

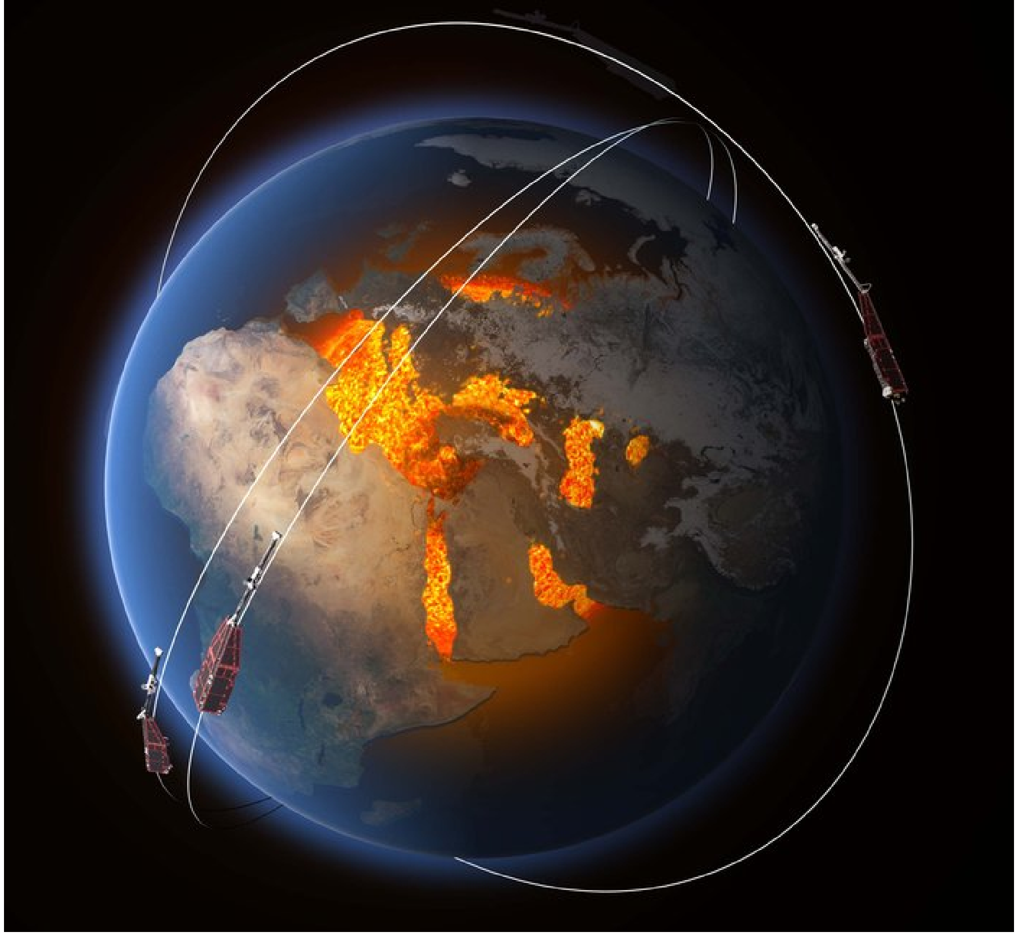
- Spherical harmonic model (n=790) inverted from EMAG2v3
- Linear algorithm fully tested with synthetic data
- Backus effect ~ a few tens of nT near the dip-equator (mostly on Y, Z)



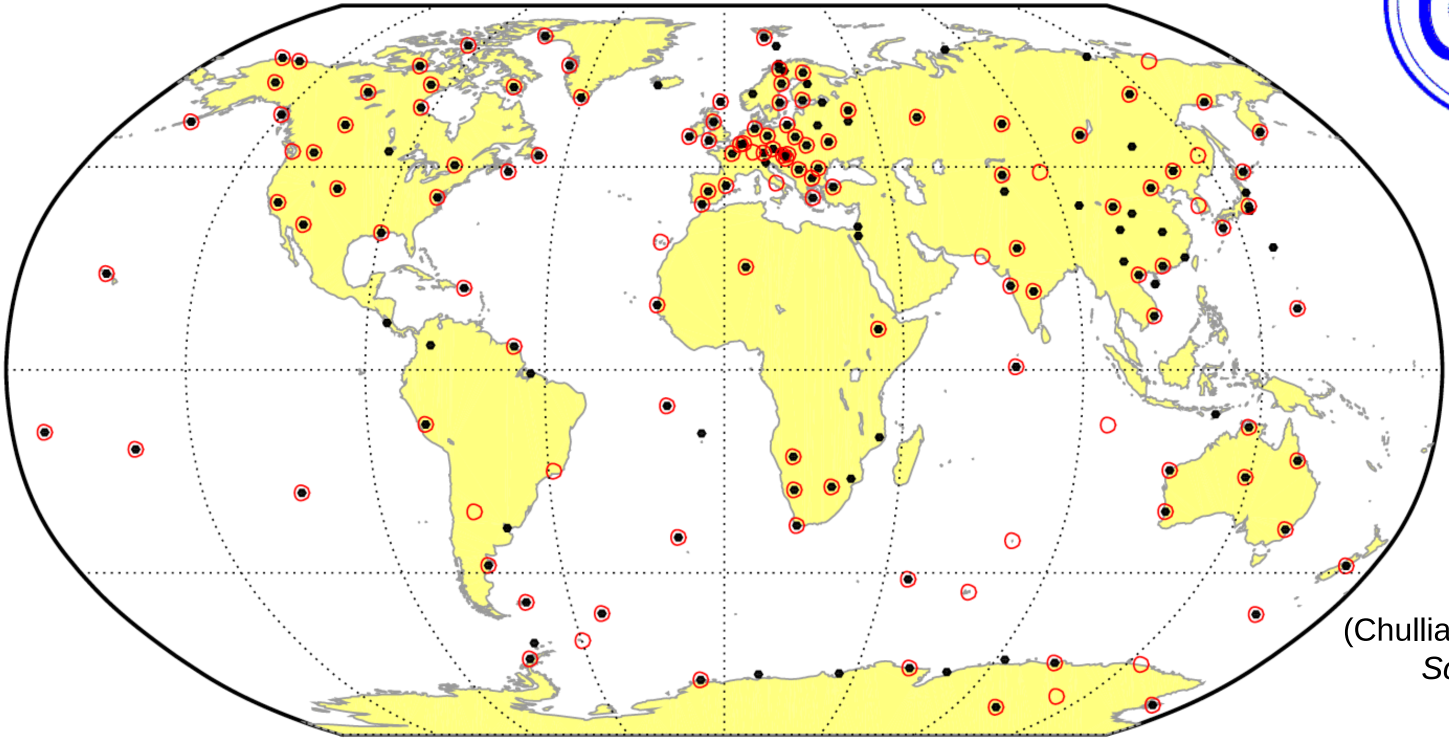
NCEI790 – HDGM (crustal), Declination



The Swarm Constellation



Most data-delivering **observatories** are now part of INTERMAGNET.

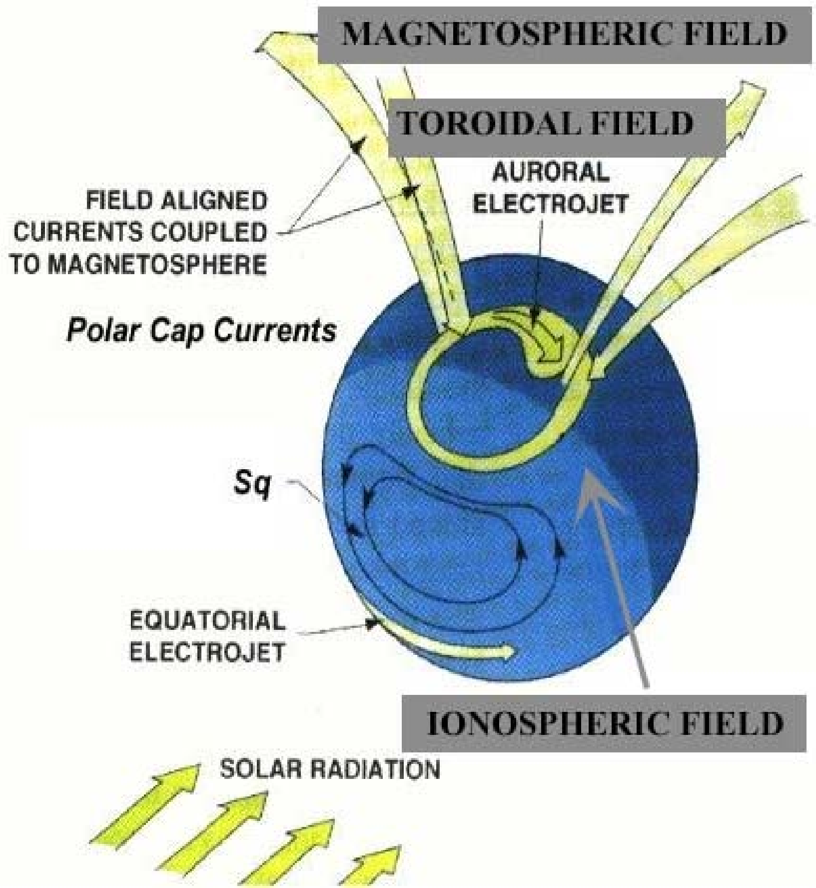


(Chulliat *et al.*, *Space Sci. Rev.*, 2017)

Black dots: observatories having distributed 2012 data through WDC
Red circles: INTERMAGNET observatories (as of October 2015)

Ionospheric Current Systems

- Diurnal variations at mid (Sq) and low (EEJ) latitudes are fairly regular
  - Seasonal variation
  - Solar cycle variation
  - Day-to-day variation (irregular)
- Polar cap currents and auroral electrojet are
  - More intense
  - Less predictable due to direct coupling to magnetosphere



Sq+EEJ Climatological Model

- Describes global Sq & EEJ fields and their *average* temporal variations (diurnal, seasonal)
- Pre-determined, linear solar cycle (F10.7) dependence
- Primary Sq+EEJ field at ground and satellite altitudes assumed to be generated by a thin current sheet at 110 km altitude
- Secondary (induced) field modeled using a 2.5D mantle conductivity model
- Current model does not describe:
  - High-latitude ionospheric fields
  - Non-seasonal day-to-day variations
  - Non-solar-cycle year-to-year variations

$$V_1(r, \theta_d, \phi_d, t, t_m) = (1 + N \times F_{10.7}) \sum_{s=s_{min}}^{s_{max}} \sum_{p=p_{min}}^{p_{max}} \sum_{n=1}^{N_{max}} \sum_{m=0}^{M_{max}} a \left(\frac{r}{a}\right)^n P_n^m(\theta_d) \left\{ \left[q_{nsp}^{m(c)} \cos m\phi_d + s_{nsp}^{m(c)} \sin m\phi_d \right] \cos(\omega_s st + \omega_p pt_m) + \left[q_{nsp}^{m(s)} \cos m\phi_d + s_{nsp}^{m(s)} \sin m\phi_d \right] \sin(\omega_s st + \omega_p pt_m) \right\}$$

$$\text{for } a < r < a + h$$

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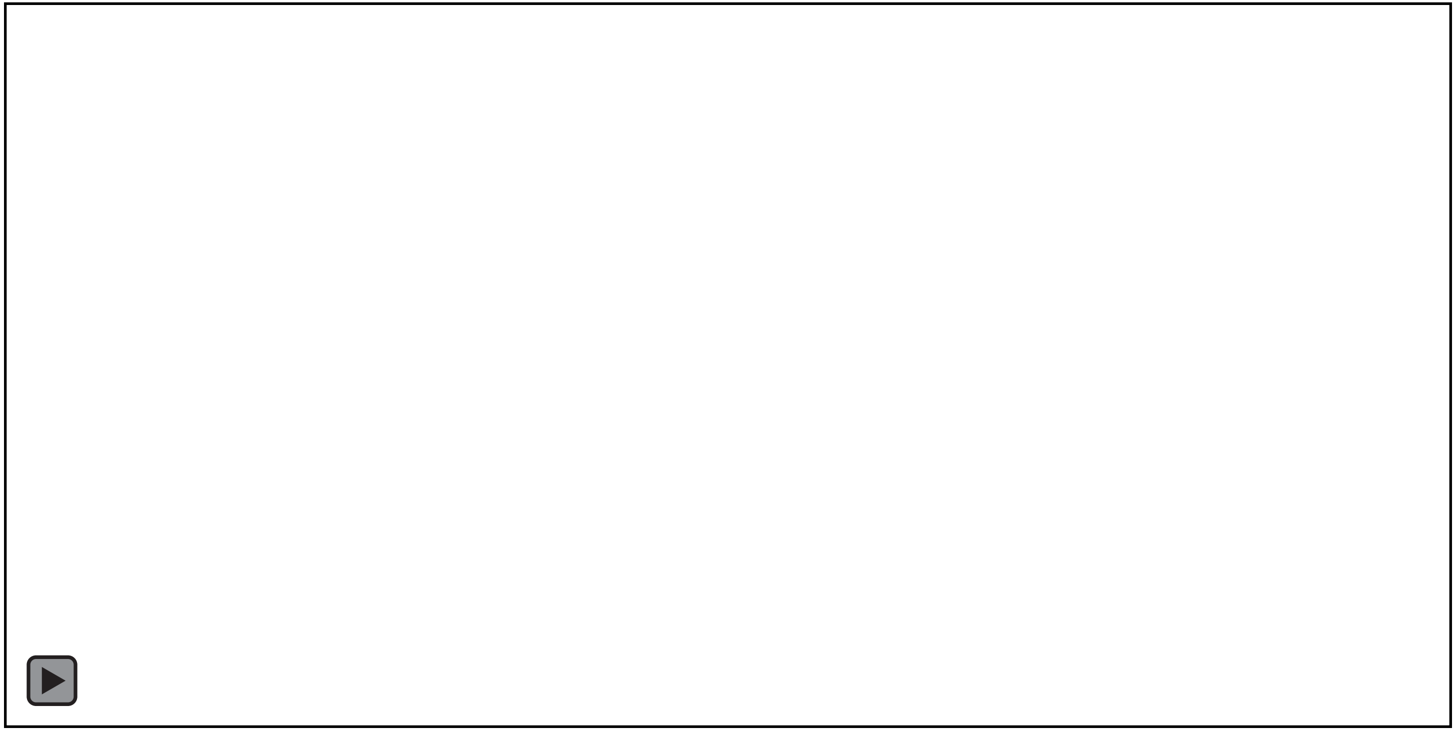
$$\text{for } r > a + h$$

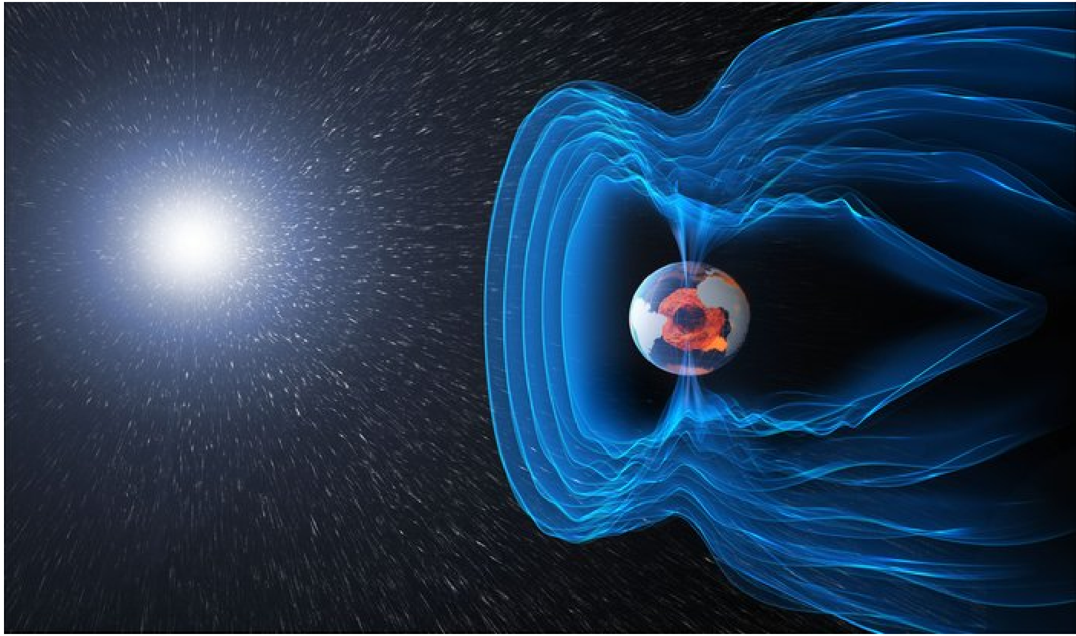
(Chulliat *et al.*, *Earth Planets Space,* 2017)



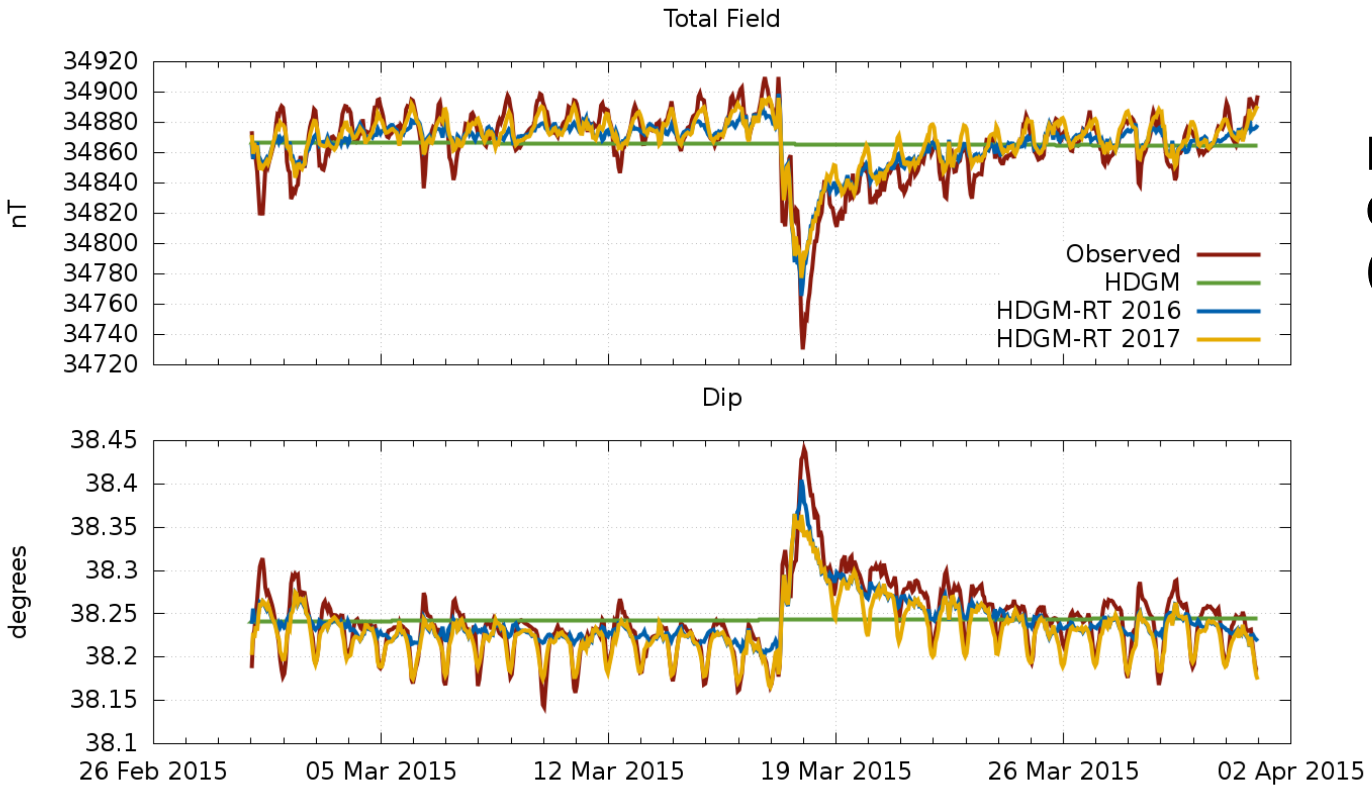
Equivalent currents in Spring (April 1). A 13.9 kA current flows between the contours.

Real-Time Magnetospheric Field

- Model developed from CHAMP satellite data (Maus & Lühr, 2005, 2010)
- Cloud based real-time implementation (Nair *et al.*, 2015)
- USGS real-time Dst* index (ground observatories) (1-min)
- Real-time ACE/DSCOVR solar wind measurements (1-min)

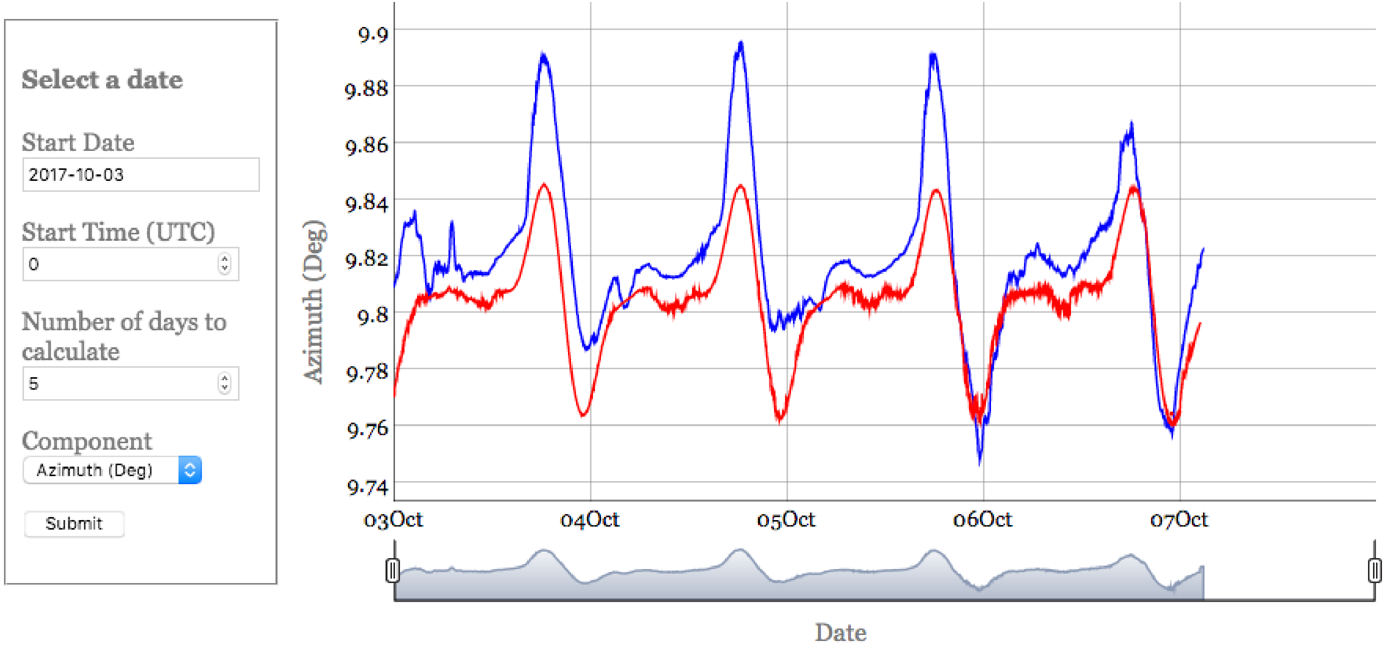


Combining Ionospheric and Magnetospheric Field Models



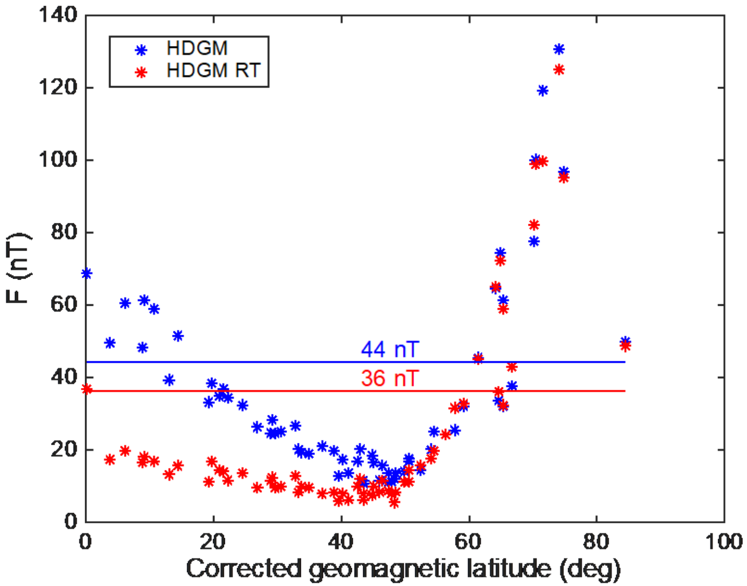
Honolulu Observatory (USGS)

Real-Time Validation at Honolulu



Real-time validation: https://www.ngdc.noaa.gov/geomag/HDGM/hdgm_rt.html

Disturbance Field Error Reduction



March 2015, all magnetic conditions

Model	F (nT)	D (deg)	I (deg)	X (nT)	Y (nT)	Z (nT)	N obs
With RT	9.2	0.03	0.01	11.6	10.0	7.2	58
No RT	18.5	0.04	0.03	24.7	16.9	10.5	58

2014-2015, all magnetic conditions, Mag Lat < 50 deg.

Summary and Outlook

- Significant increase of NOAA trackline data holdings since 2010
- New global anomaly grid at 2-arcmin resolution
  - includes new data and more recent satellite-based model
  - provides regional uncertainties
- Ongoing development of new, higher resolution (n>720) crustal field models
- New satellite-based, climatological, ionospheric field model provides daily variation at mid- and low-latitudes
- Combining real-time magnetospheric & climatological ionospheric field models reduces random error by ~50% at mid- and low-latitudes