

Recent Advances in Crustal and Disturbance Field Modeling

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Rick Saltus, Adam Woods, Benny Poedjono

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)

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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

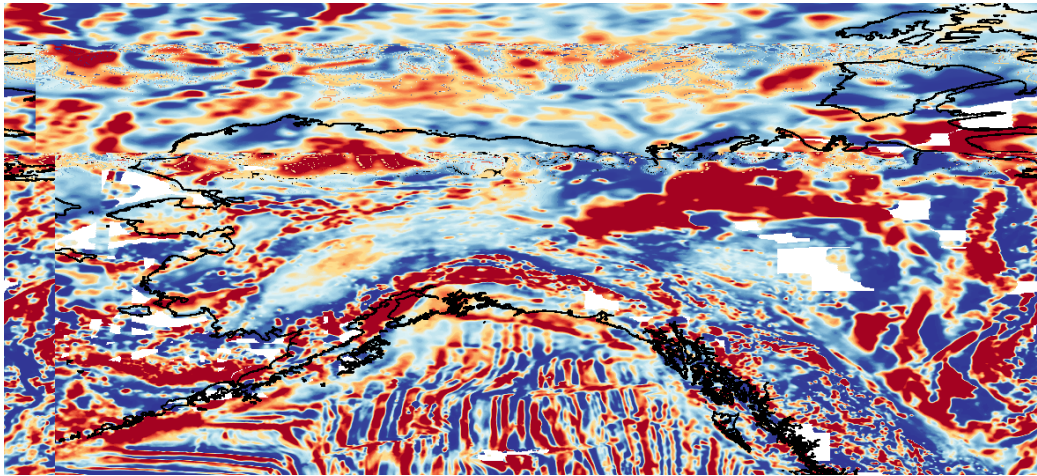
NOAA/NCEI GEOphysical Data System (GEODAS)

- 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

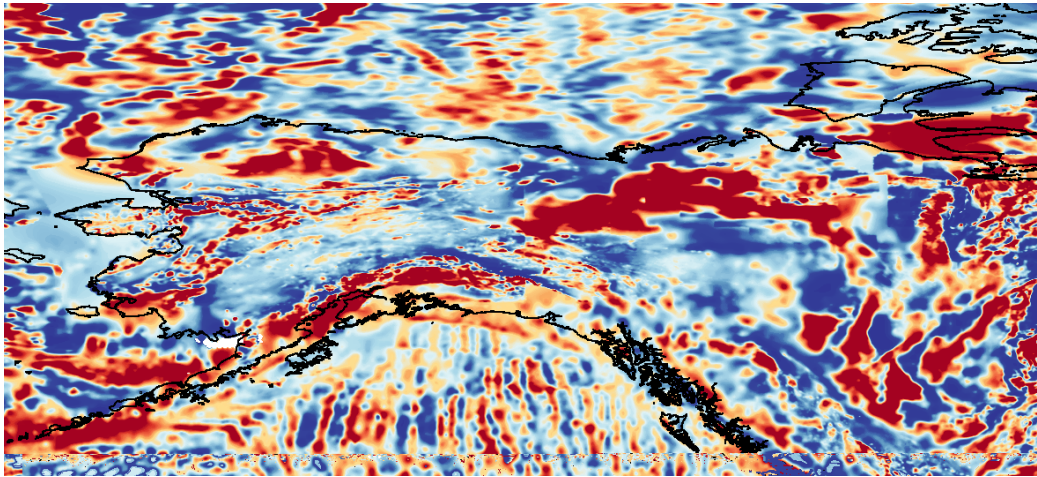
EMAG2v3

- 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](https://doi.org/10.7289/V5H70CVX)

Alaska



EMAG2 (2009)



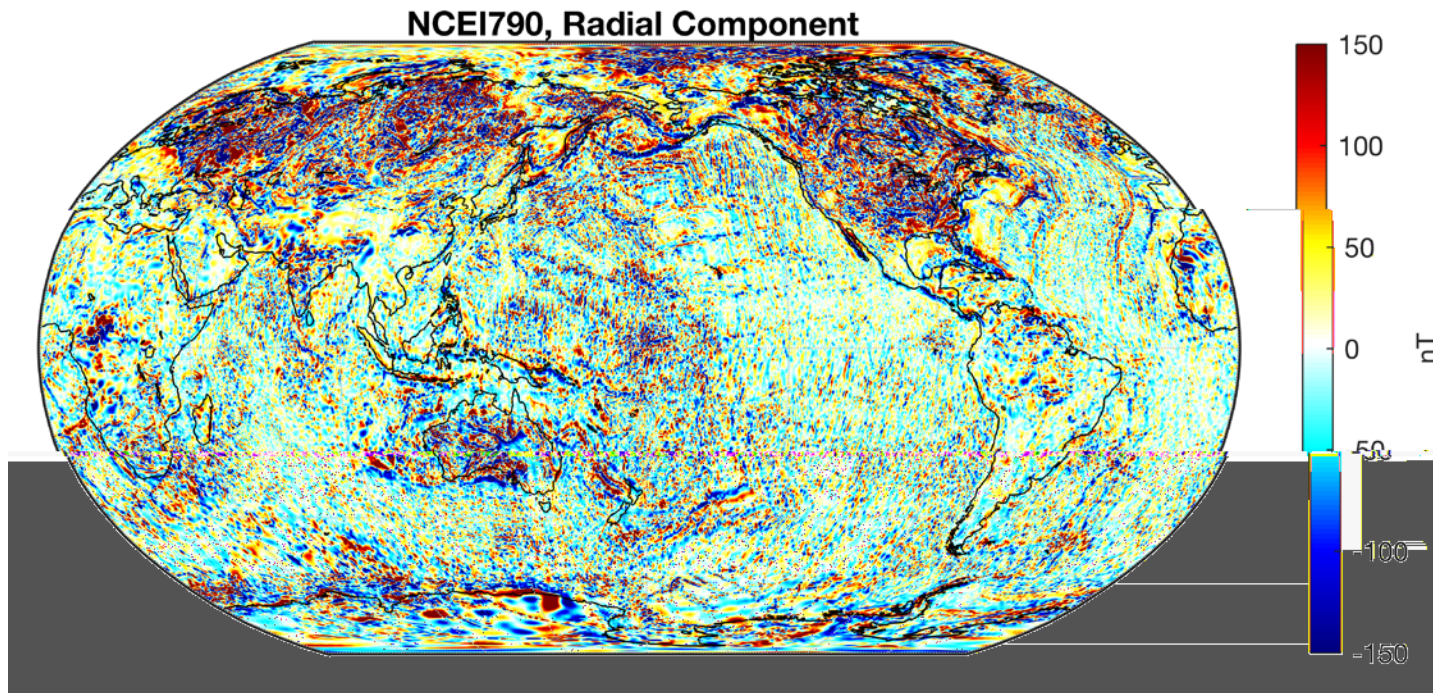
EMAG2v3 (2017)

Global Map of Uncertainties

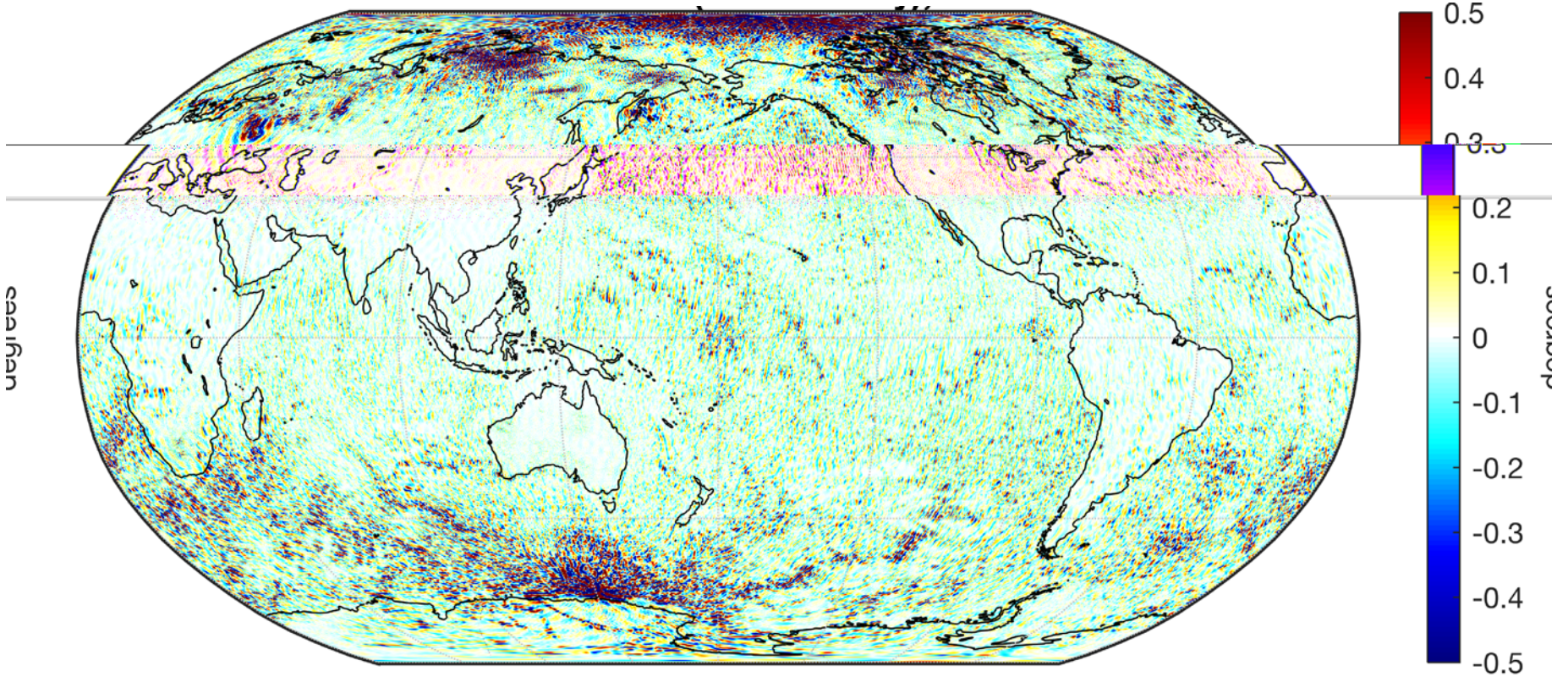
- Reflects heterogeneity in survey data quality
- 1σ error

NCEI790

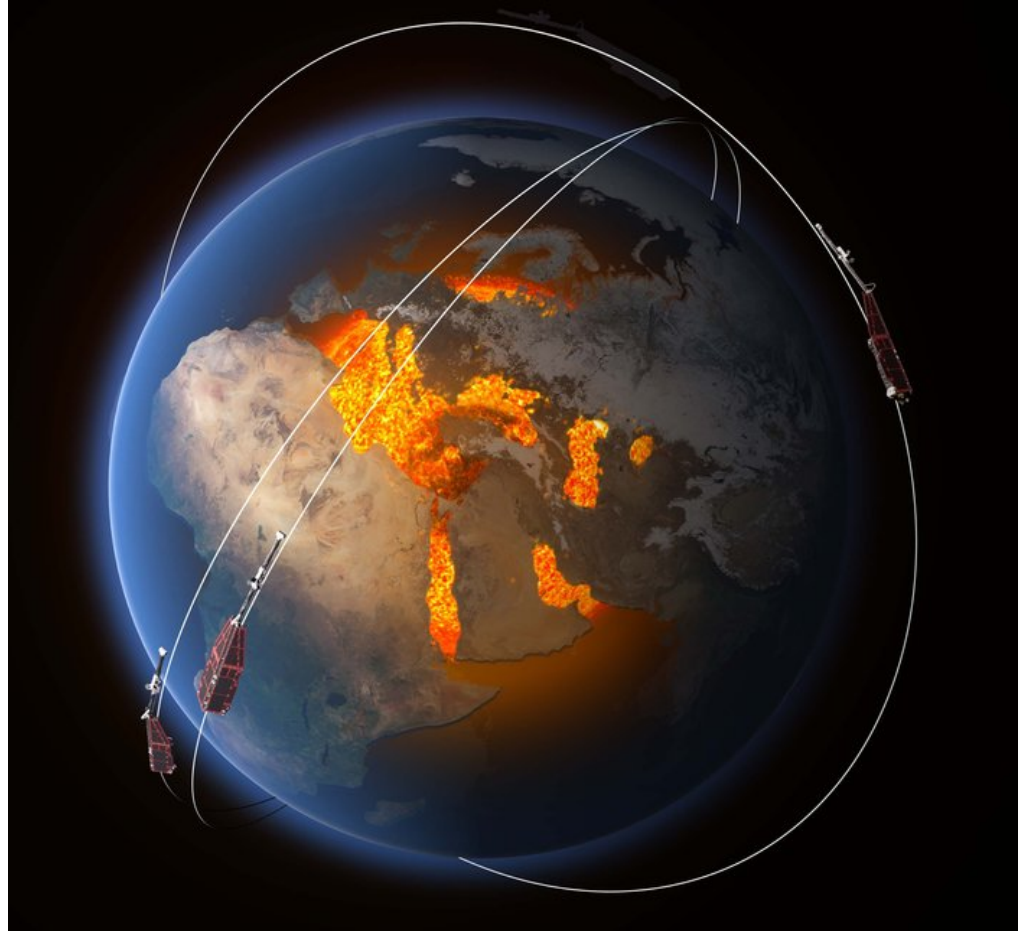
- Spherical harmonic model ($n=790$) inverted from EMAG2v3
- Linear algorithm fully tested with synthetic data
- Backus effect ~ a few tens of nT near the dip-equator (mostly on Y, Z)



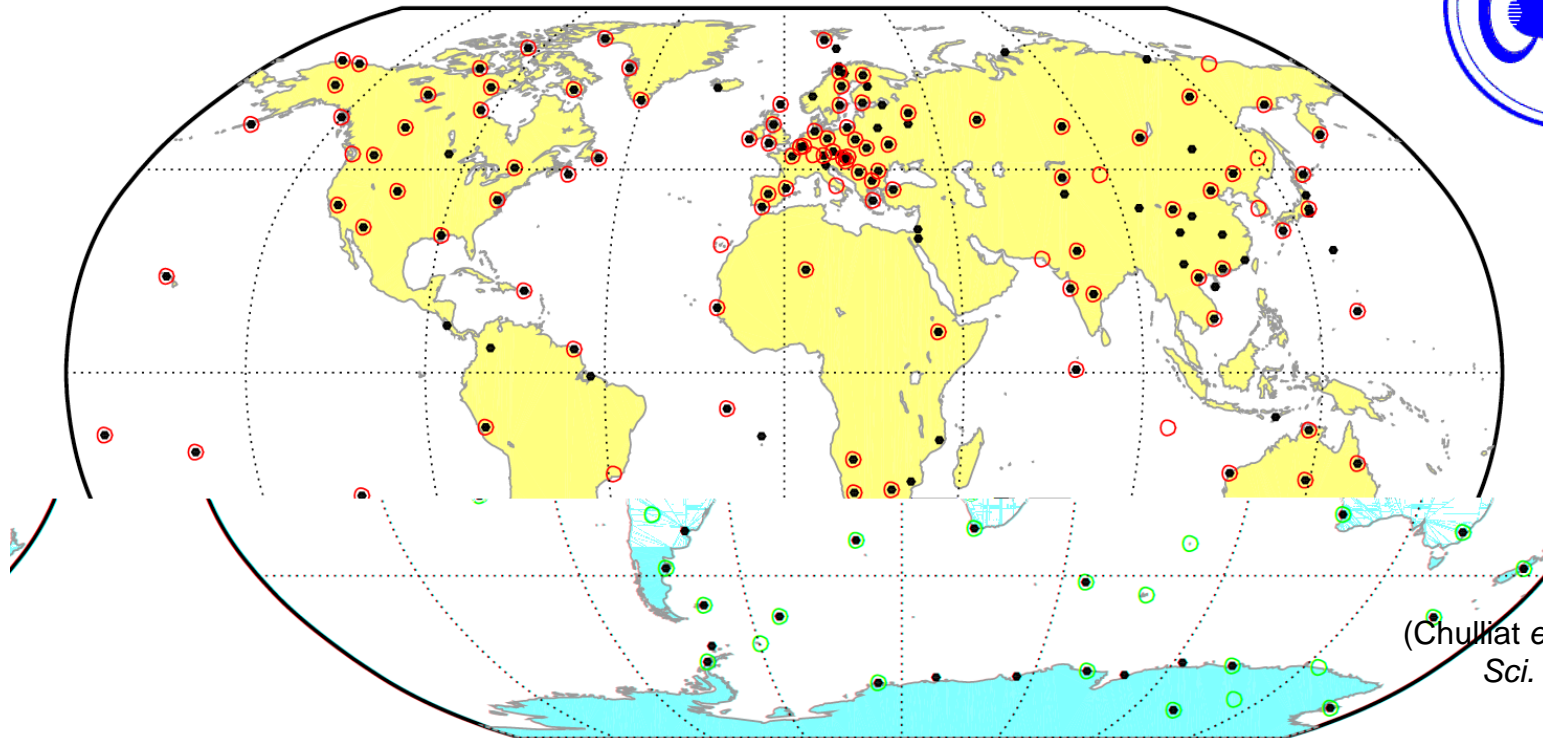
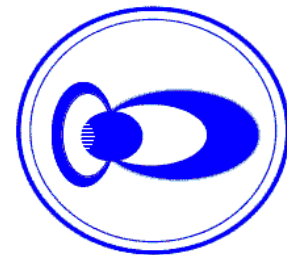
NCEI790 – HDGM (crustal), Declination



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)

46th General Meeting
October 12th, 2017
San Antonio Texas, USA

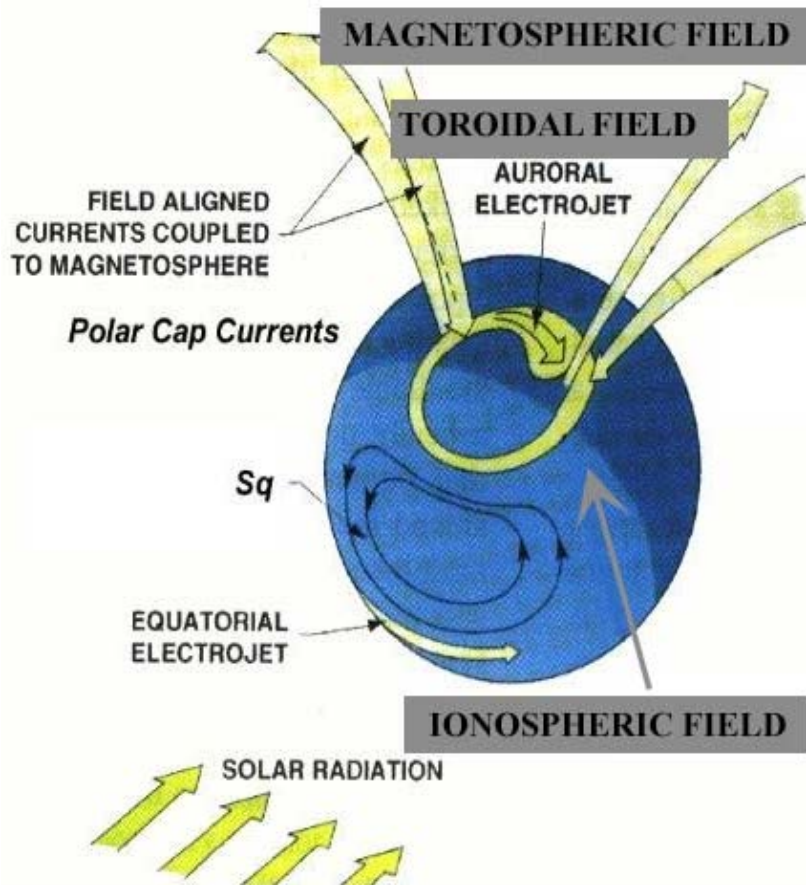
Wellbore Positioning Technical Section



The Industry Steering Committee on Wellbore
Survey Accuracy (ISCWSA)

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

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

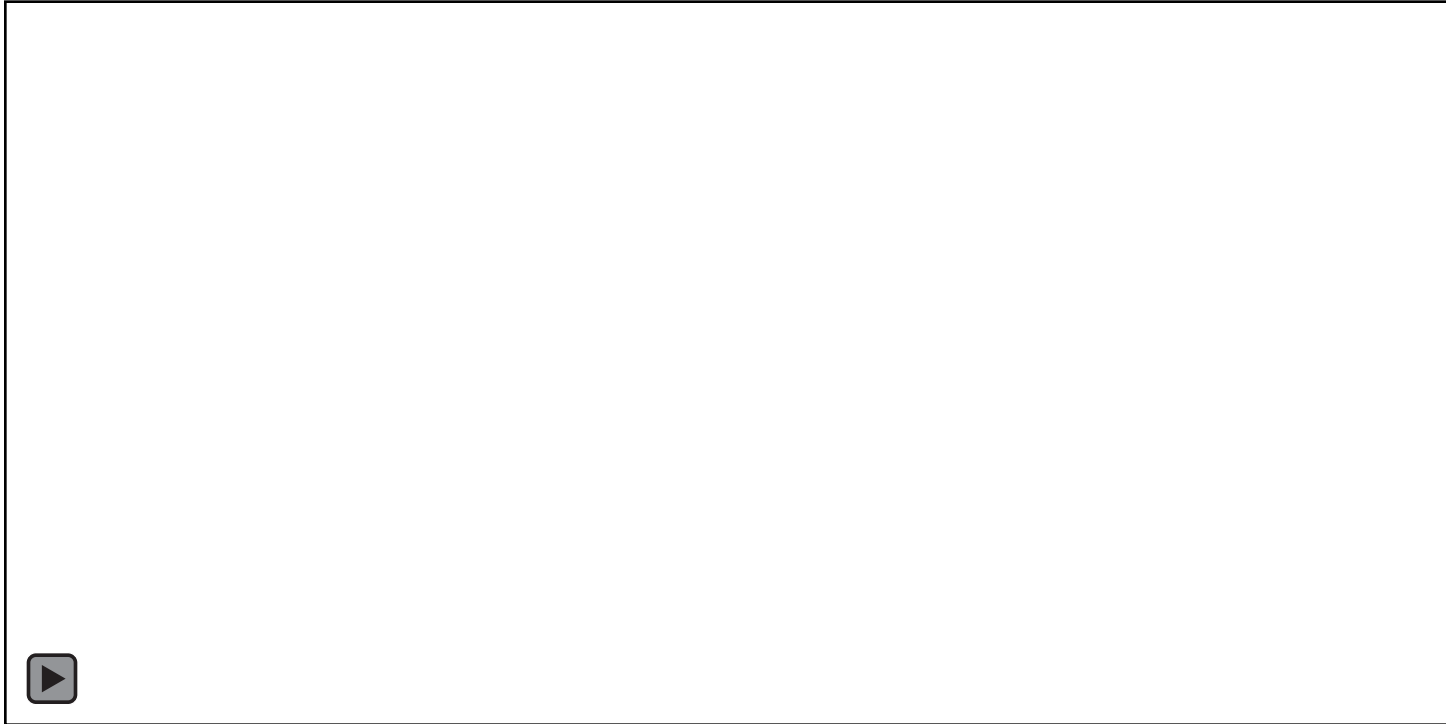
for $a < r < a + h$

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

for $r > a + h$

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

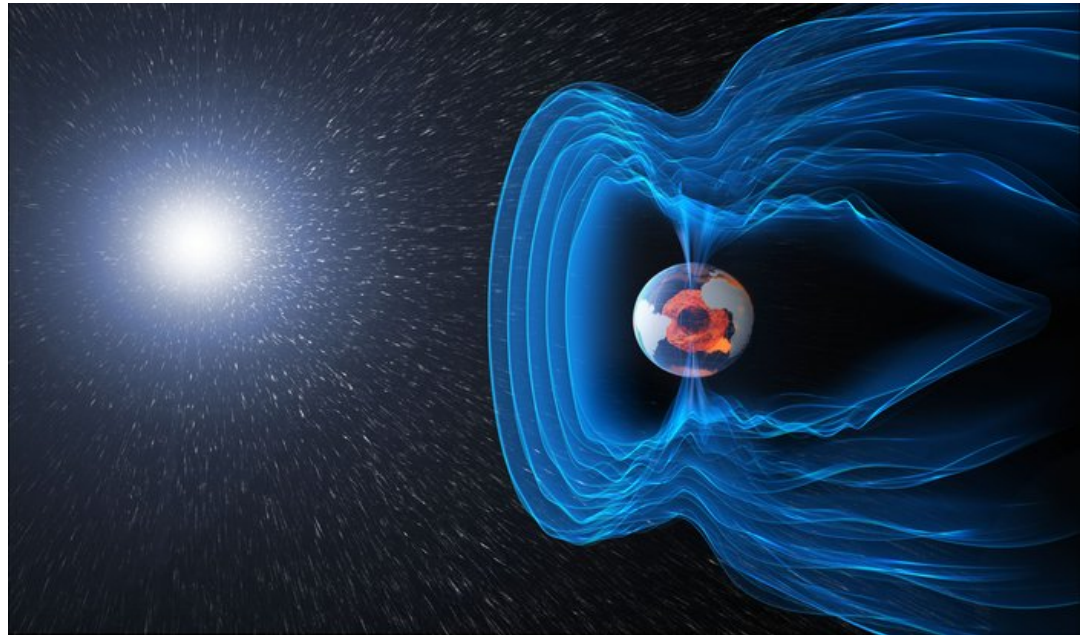




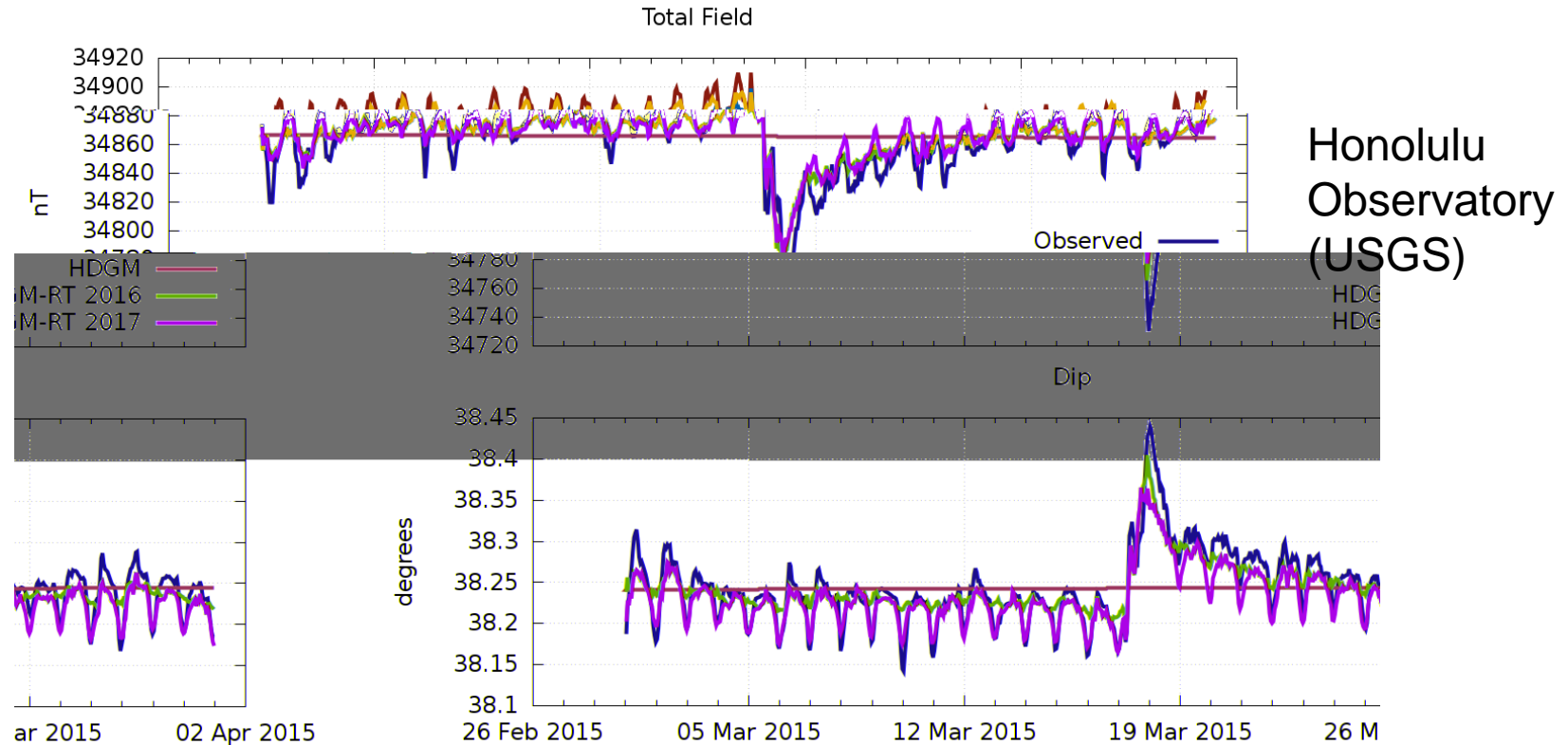
Equivalent currents in Spring (April 1). A 13.9 kA current flows between the contours.

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



Real-Time Validation at Honolulu

Select a date

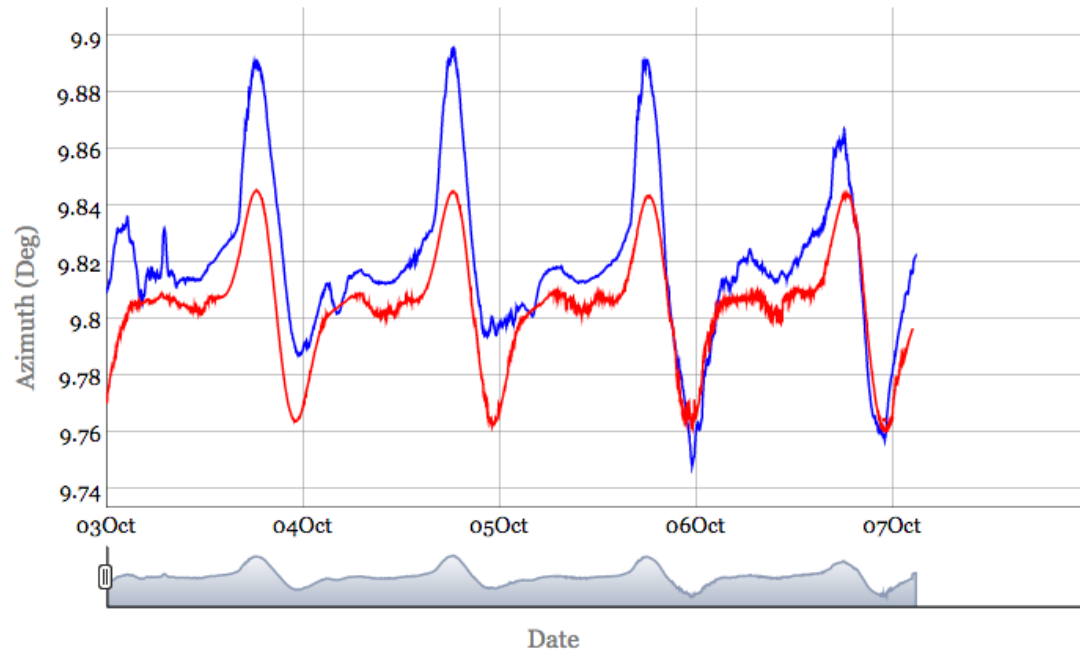
Start Date
2017-10-03

Start Time (UTC)
0

Number of days to calculate
5

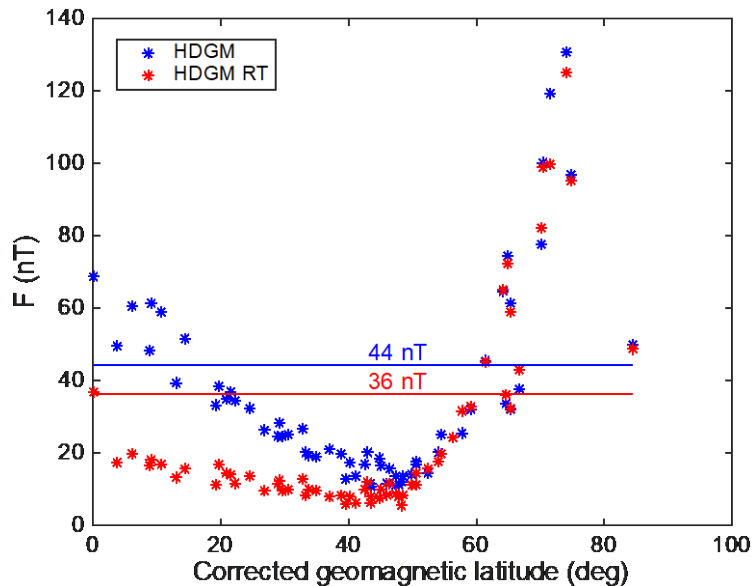
Component
Azimuth (Deg)

Submit



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

Disturbance Field Error Reduction



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