Recent secular variation and an update to the World Magnetic Model

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NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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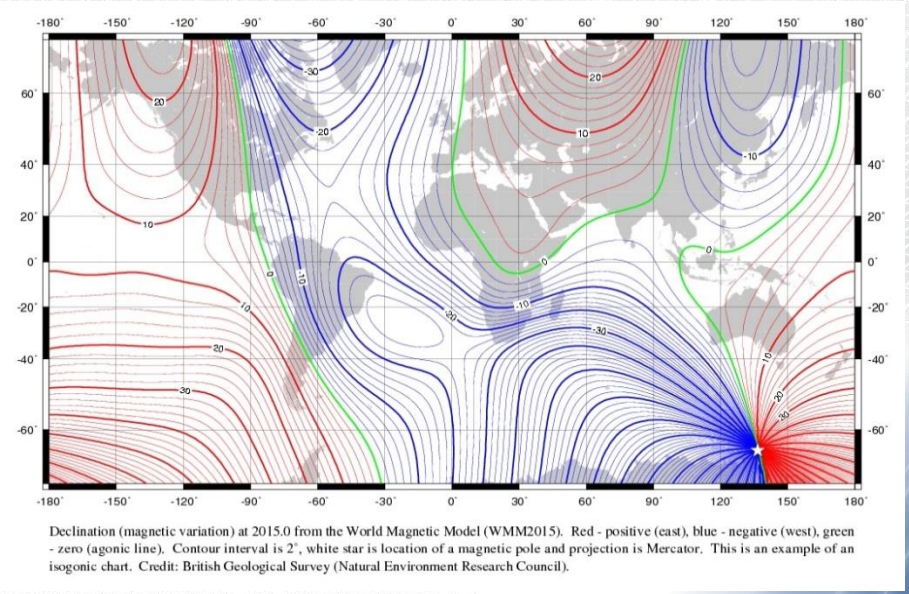
Overview

- Context:
  - World Magnetic Model (WMM)
  - SV, SA and predictive models
- Need for out-of-cycle WMM
- Field model build and validation
- SV analysis
- Summary

Context: World Magnetic Model (WMM)

- Jointly produced by BGS (UK) and NOAA (USA)
- Predictive large scale (L_{max}=12) core field model
- Includes error model
- Standard model for NATO, DoD, MoD, IHO
- Widely used for civilian navigation systems, e.g. Android, iOS
- Produced on 5-year cycle

WMM2015 declination



Declination (magnetic variation) at 2015.0 from the World Magnetic Model (WMM2015). Red - positive (east), blue - negative (west), green - zero (agonic line). Contour interval is 2°, white star is location of a magnetic pole and projection is Mercator. This is an example of an isogonic chart. Credit: British Geological Survey (Natural Environment Research Council).

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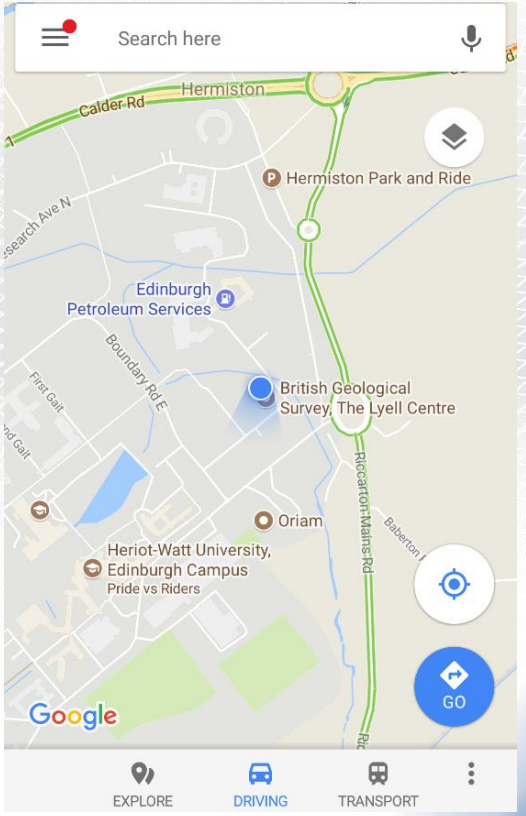
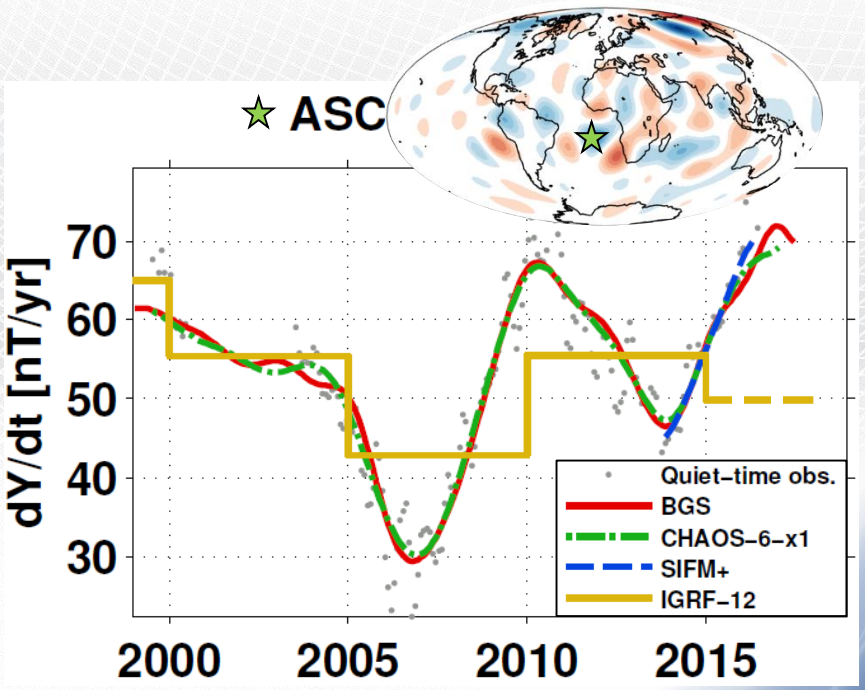


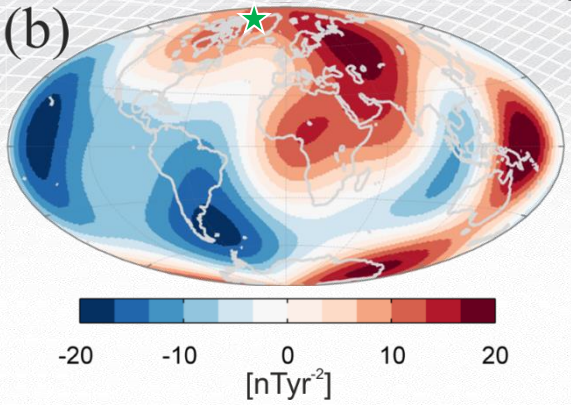
Context: SV, SA and field prediction

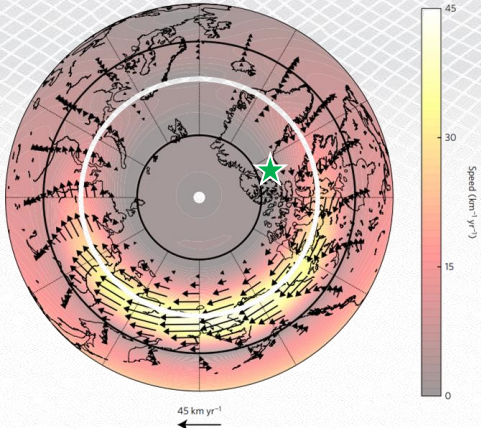
- First two time derivatives of field are
  - **S**ecular **V**ariation
  - **S**ecular **A**cceleration
- Field models are retrospective as we don't understand core physics
- Field models are least reliable at ends
- IGRF and WMM assume no SA

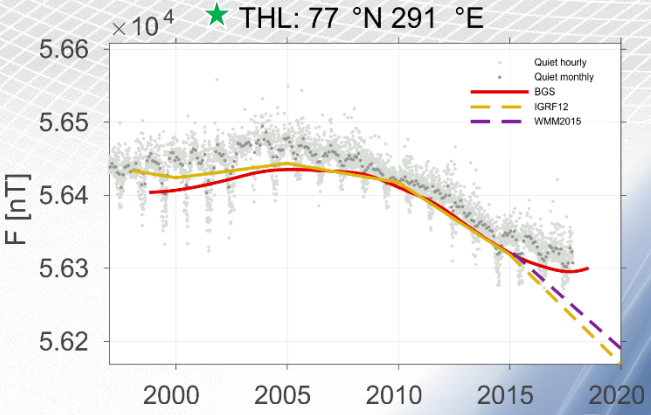


Need for out-of-cycle model

- Recent SV, at high Northern latitudes in particular, has strayed from 2015 predictions, i.e. not-constant SV
- Jerks identified in 2014—2016 [Torta et al 2015, Brown et al 2016], compatible with pulsing SA and wave propagation of Chulliat et al [2015]
- Northern polar “core jet” identified [Livermore et al 2016]





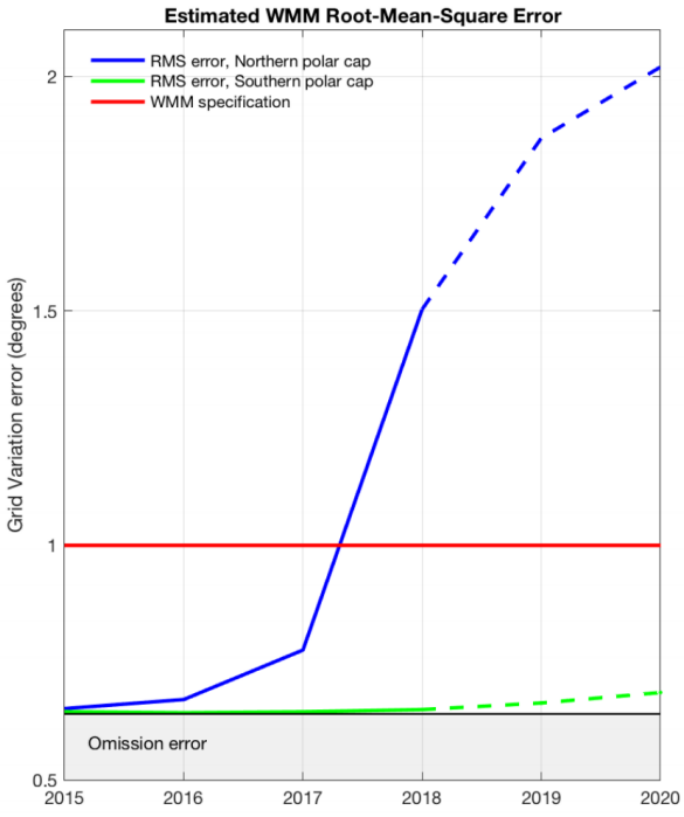


2014 jerk SA: Brown et al 2016, Spacebooks Online

Core jet: Livermore et al 2016, Nature Geosci.

Need for out-of-cycle model

- Non-constant SV is common but currently unpredictable
- WMM designed to meet *“NATO Standardization Agency, 2011. STANAG 7172 Use of Geomagnetic Models (2nd ed).”*
- Specifies tolerances in model accuracy – RMSE 1° declination or grid variation (GV) at >|55°| latitude
- GV = declination ± longitude



WMM2015 Performance Whitepaper, 21-Mar-2018, NOAA/NCEI

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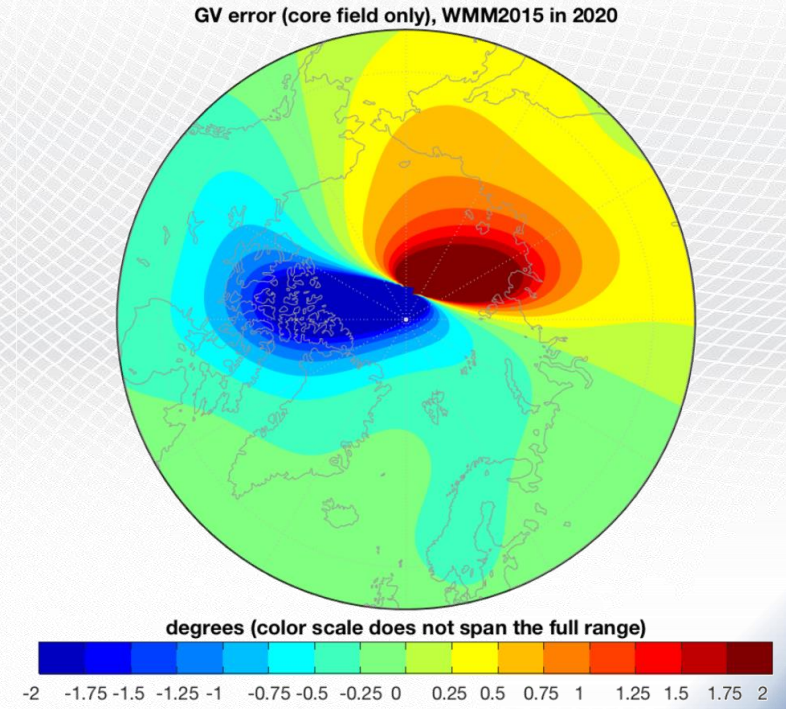
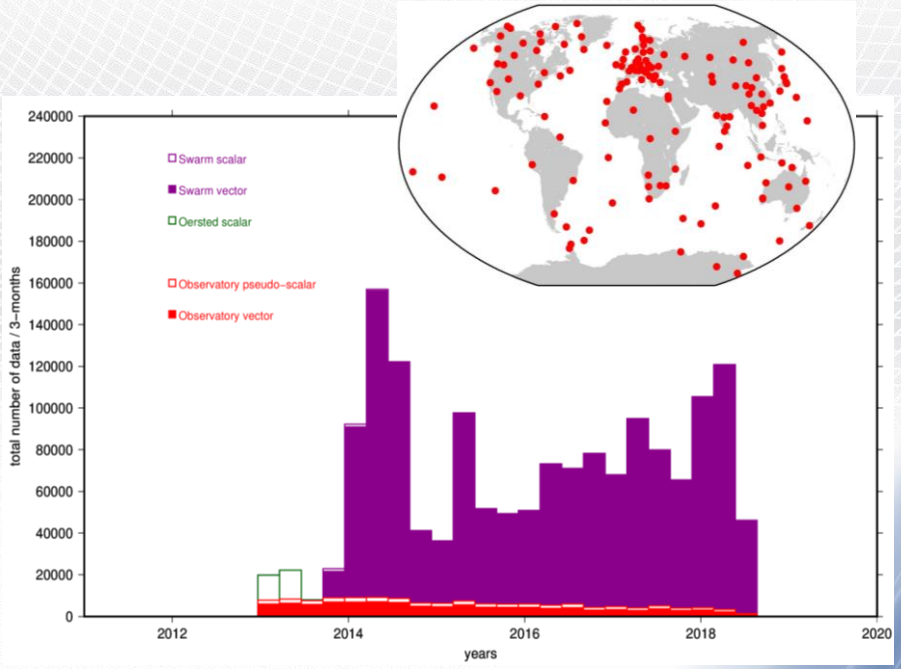


WMM2015 Performance Whitepaper, 21-Mar-2018, NOAA/NCEI

Most importantly: we need Swarm & Obs.!

- We can only assess model error estimates by comparing to more up-to-date data and models
- New data *must* be promptly available to develop models and keep track of model performance
- **Swarm and observatory network make this possible**



Field model build

- BGS and NOAA produce up-to-date field models
- Model describe internal and external fields
- Snapshot WMM style models derived from each
- Final models combined and validated

BGS model:

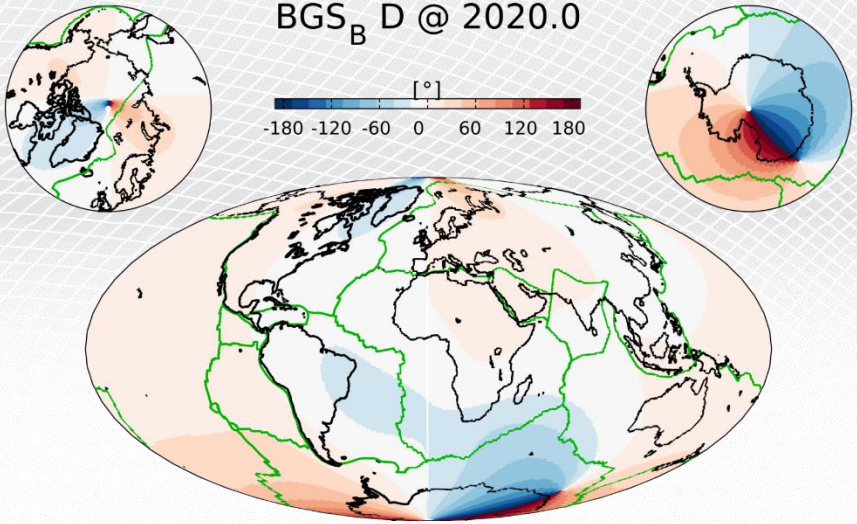
- Ørsted, Swarm A, B, C, Observatories
- Core L_{max}=15, order-6 spline, 6-month knots
- Damp B_r integral of 3rd time derivative, 2nd time derivative at ends, at CMB

NOAA model:

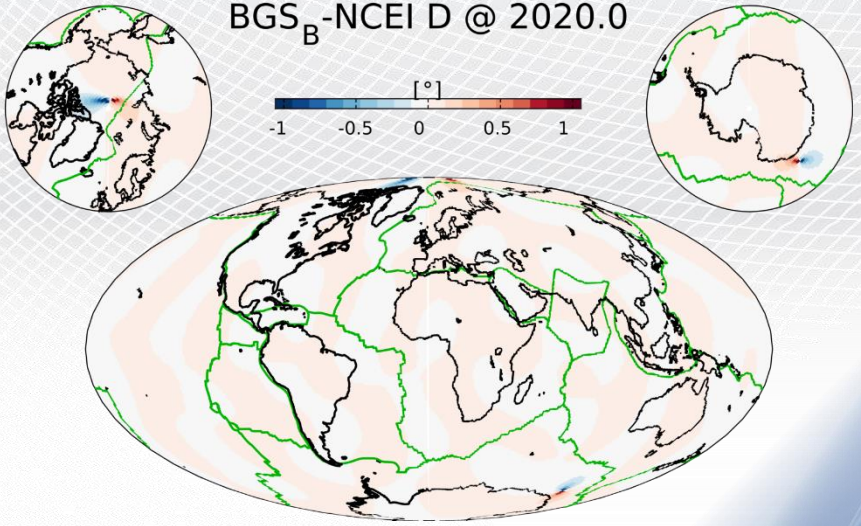
- Swarm A, B
- Core Taylor expansion MF L_{max}=35, SV L_{max}=15, SA L_{max}=10
- Damp B_r integral of 1st, 2nd time derivatives at CMB

Field model validation

BGS declination

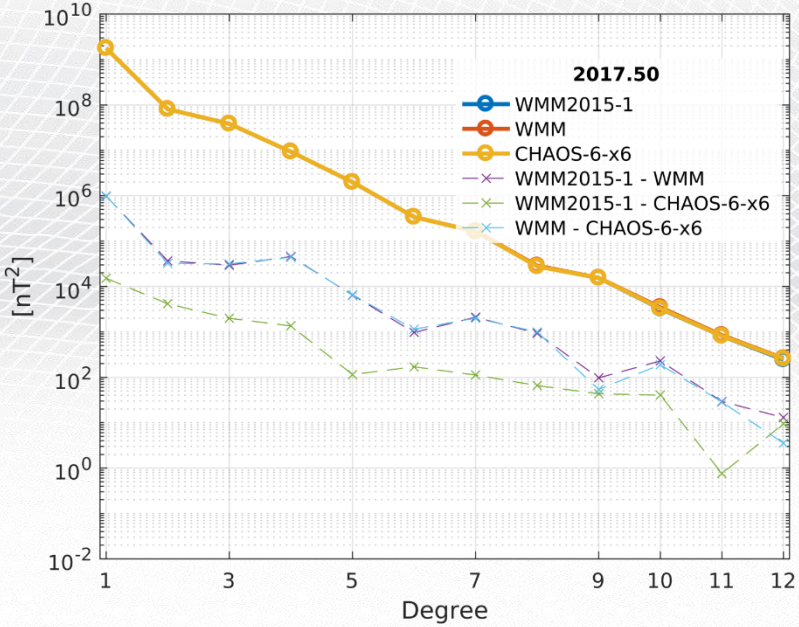


Δ(BGS – NOAA) declination

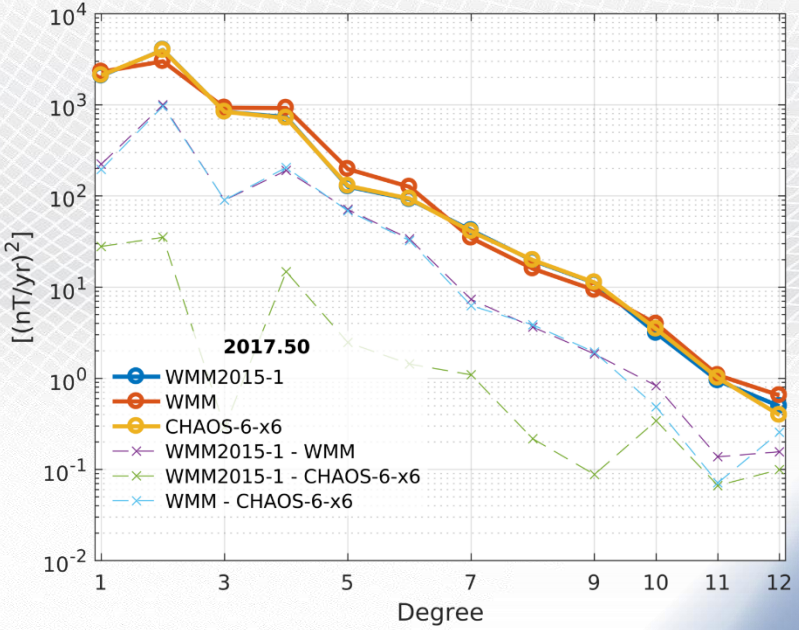


Field model validation

MF @ 2017.5

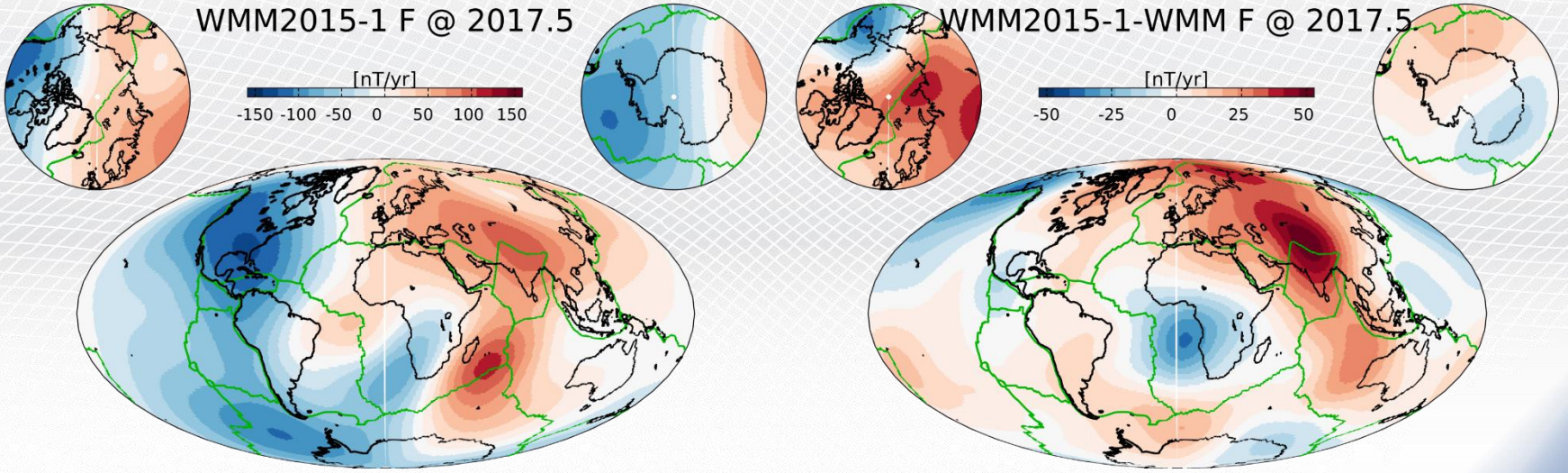


SV @ 2017.5



SV analysis: improvement in WMM

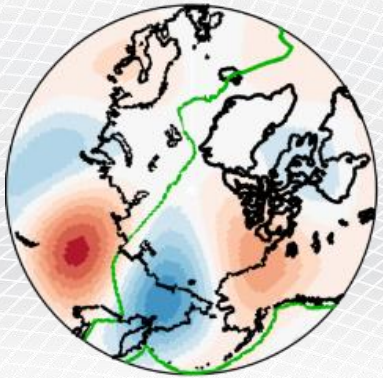
dF/dt **Estimated improvement in dF/dt**



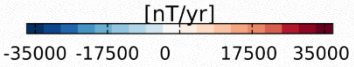
- Model likely within WMM spec. throughout 2015 to 2020
- Recent SV (left) and estimate of regions of likely improvement (right)

SV analysis: effect of core jet

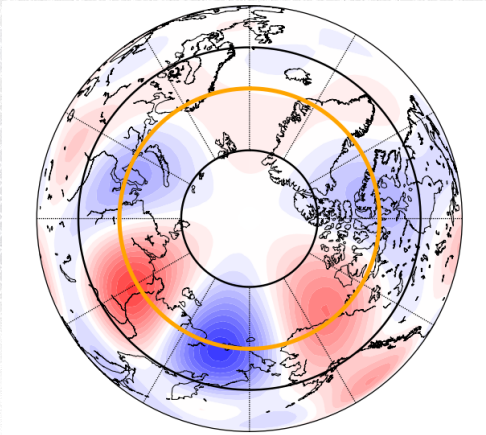
2015 SV @ CMB

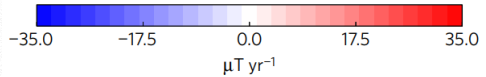


B_r @ 2015.0

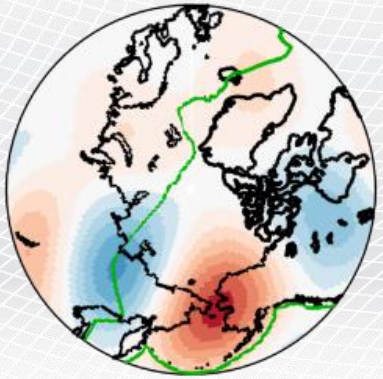


Livermore et al 2016
jet model SV @ CMB

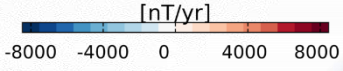




ΔSV 2015 to
2017.5 @ CMB



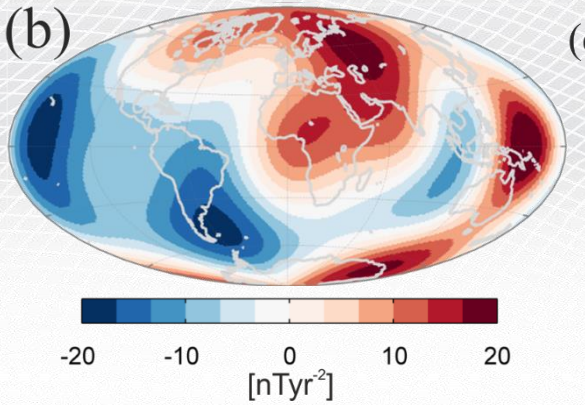
B_r Δ(2017.5-2015.0)



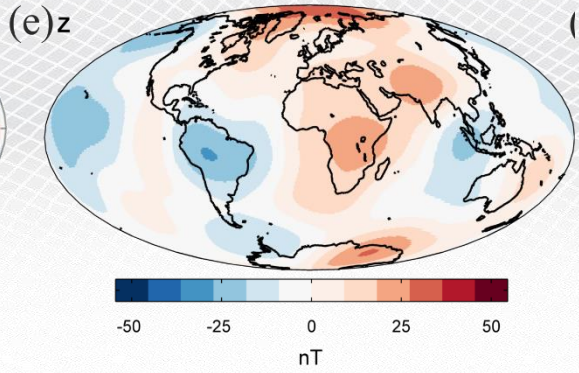
- ΔSV between 2015 and 2017.5 appears to corresponds to an evolution of the jet signal

SV analysis: 2014 jerk effect

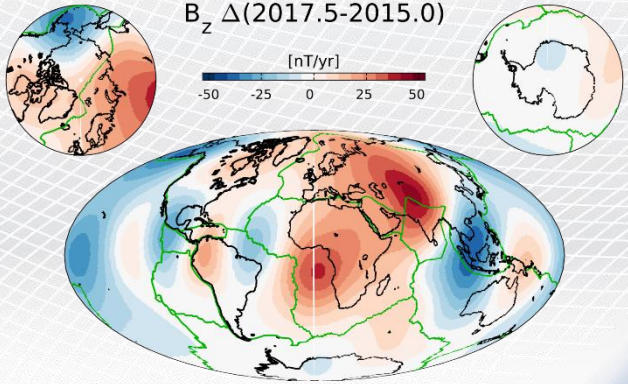
Brown et al [2016]
2014 jerk model
(observatory data)



Brown et al [2016]
IGRF-12 error
estimate after 1 year



ΔSV 2015 to 2017.5



- Morphology of the 2014 jerk and early estimates of IGRF-12 misfit are similar to the now observed field change over recent years

Summary

- SV, particularly at Northern latitudes, differs from 2015 predictions
- SA is important!
  - combination of widespread jerks in 2014 and flow acceleration of Northern jet
- An update to WMM2015 has been produced to account for this
- This process was possible because of the prompt and widespread availability of Swarm and observatory data
- A good opportunity to study the recent SV ahead of WMM and IGRF releases in 2020