British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Using core flow to forecast the short-term change of the magnetic field

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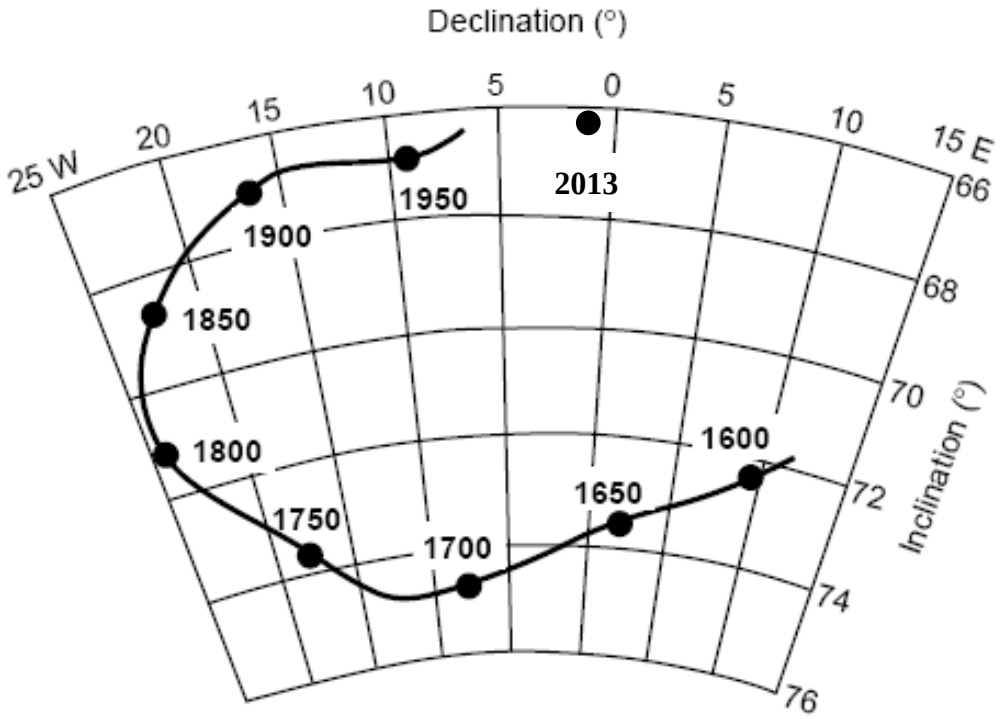
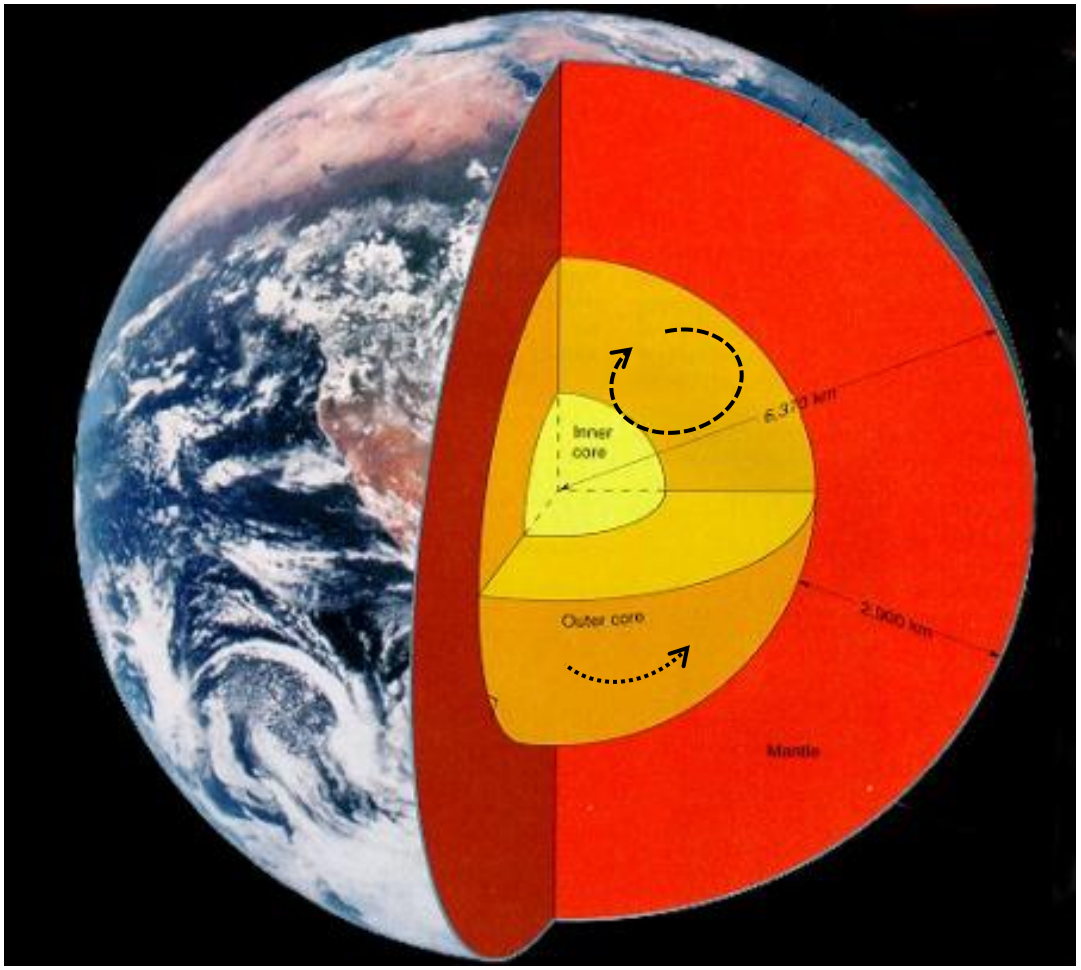
A compass in London

- Historic record of geomagnetic field direction in London, United Kingdom. Declination and Inclination in azimuthal equidistant projection.



The Liquid Outer Core



- Composition
  ~ 90% Fe
  ~ 10 % Ni, O, S, Li?

- Temperature > 3500 ˚K

- Viscosity of water on surface

- Freezing of inner core expels light elements
- Rotates every 24 hours

→ Continuously in motion

Geodynamo: motion into magnetism

Conductive fluid *in motion*

+ magnetic field

= electric currents

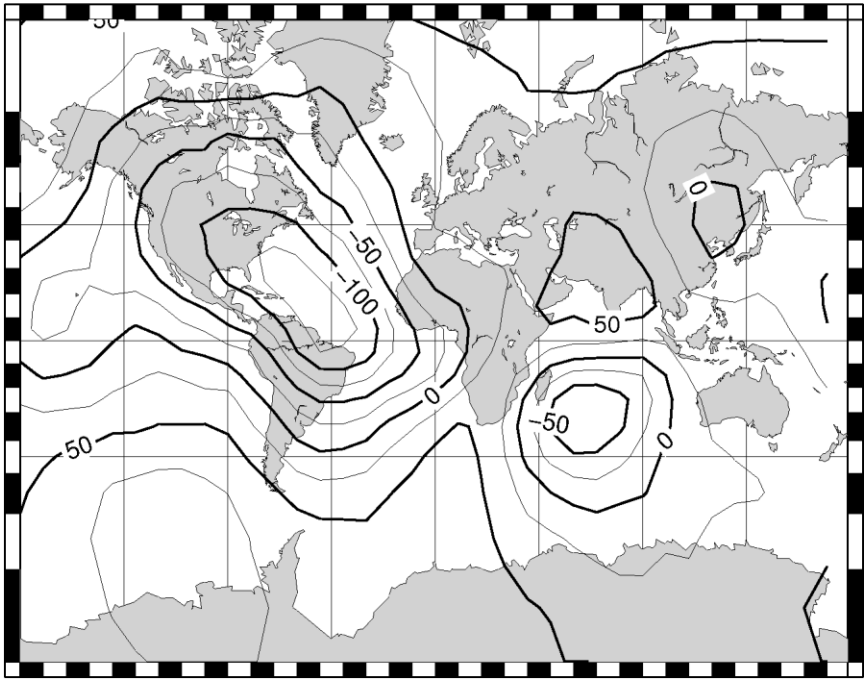
Hence the ‘geodynamo’

- Electric fields generate secondary magnetic field – this is what we observe at the surface

- Requires about 4 GW of energy (not a lot, really) for poloidal field

Magnetic field change

- Assume that the magnetic field is frozen into the liquid
- Infer **flow** from the change of the magnetic field over time
- A *classic* geophysical problem
  - Very ambiguous
  - Assumptions about the flow
  - Apply damping parameters
- Solve for flow ($\dot{\mathbf{u}}$) and acceleration ($\ddot{\mathbf{u}}$)



$$\dot{B}_r = -B_r \nabla_H \cdot \mathbf{u} - \mathbf{u} \cdot \nabla_H B_r$$

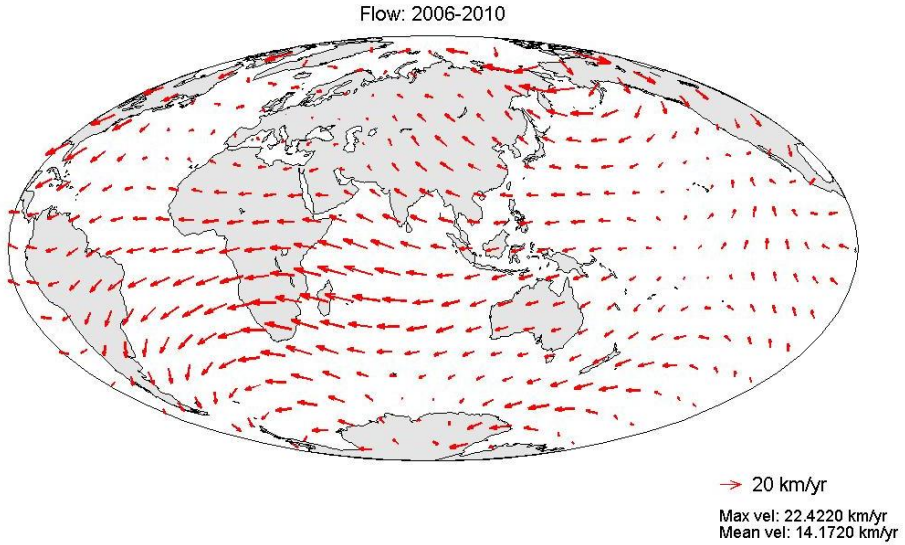
$$\ddot{B}_r = -\dot{B}_r \nabla_H \cdot \mathbf{u} - B_r \nabla_H \cdot \dot{\mathbf{u}} - \dot{\mathbf{u}} \cdot \nabla_H B_r - \mathbf{u} \cdot \nabla_H \dot{B}_r$$

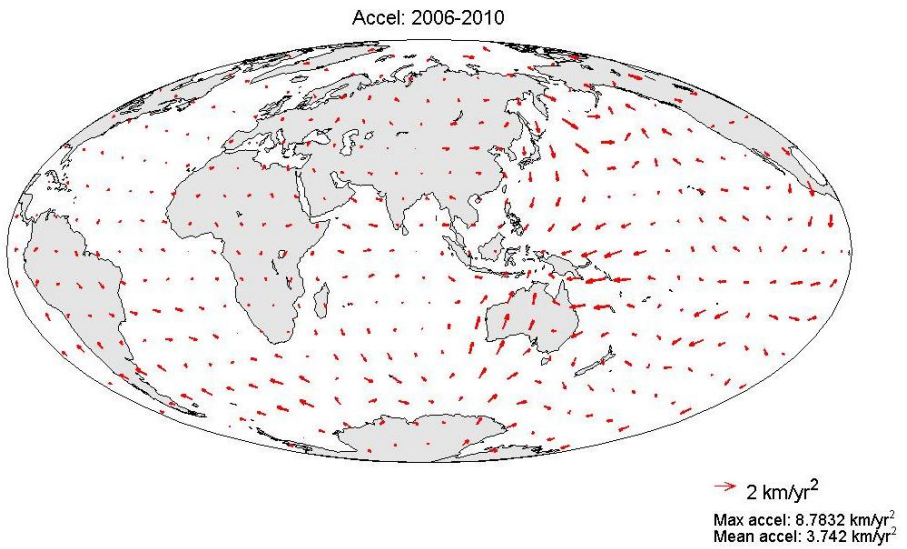
Flow and acceleration models

- Fluid flow and acceleration on the surface of the outer core are computed from the change of the main field (secular variation) and the rate of change of the secular variation (secular acceleration)

- Caveats:
  - assumption is that flow and acceleration are steady
  - requires tuning and assessment by an expert at each revision
  - will not capture very rapid changes (but no method will)

Maps of steady flow & steady acceleration





Flow

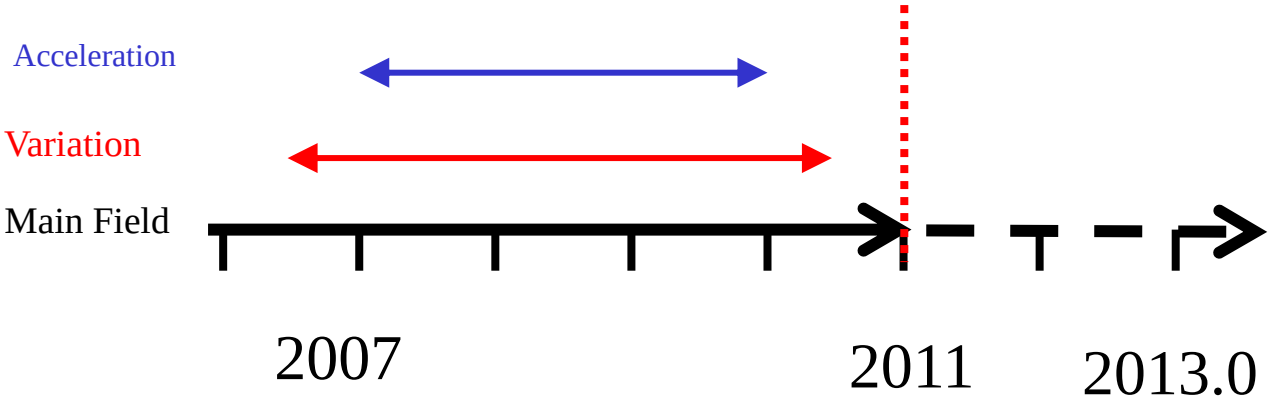
Acceleration

Mean vel: 14 km/yr

Mean acceleration: 3.7 km/yr^2

Using flow models to make forecasts

- Use a magnetic model to compute average flow and acceleration over several years (e.g. 2007 - 2011)
  - *Collect magnetic data*
  - *Make core flow models*
- Predict forwards in time from 2011.0 – 2013.0
  - *Forecast the magnetic field change*



How good is the forecast?

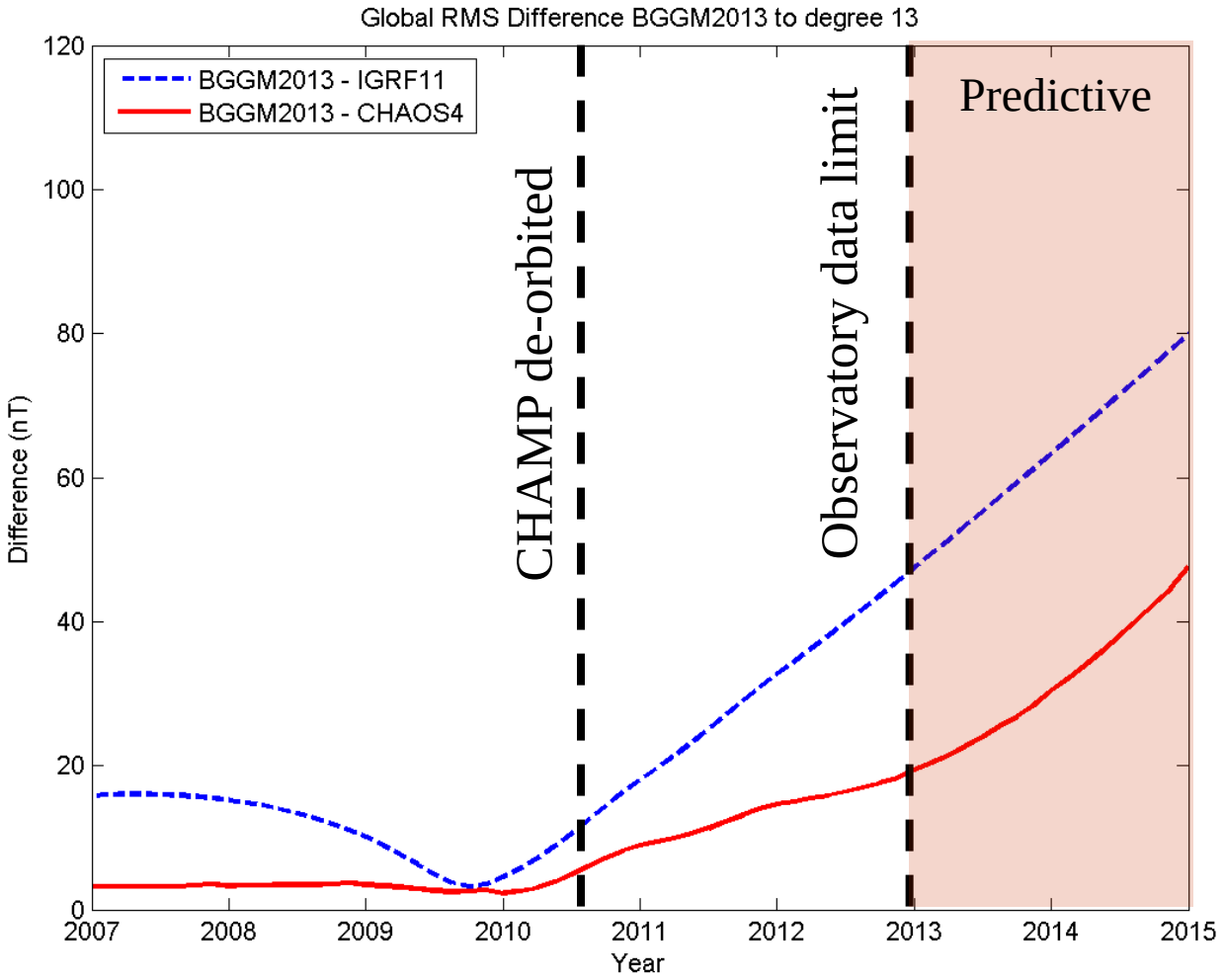
- Compare against retrospective field models
  - Are generated by different methods using different data
  - Which model is the ‘truth’ ?
  - (A bit like having two clocks with slightly different times)

- Check the fit to available observatory data for 2011.0-2013.0
  - Hourly mean values at 0200-0300 LT
  - Data still noisy
  - Fit is computed by checking *standard deviation*

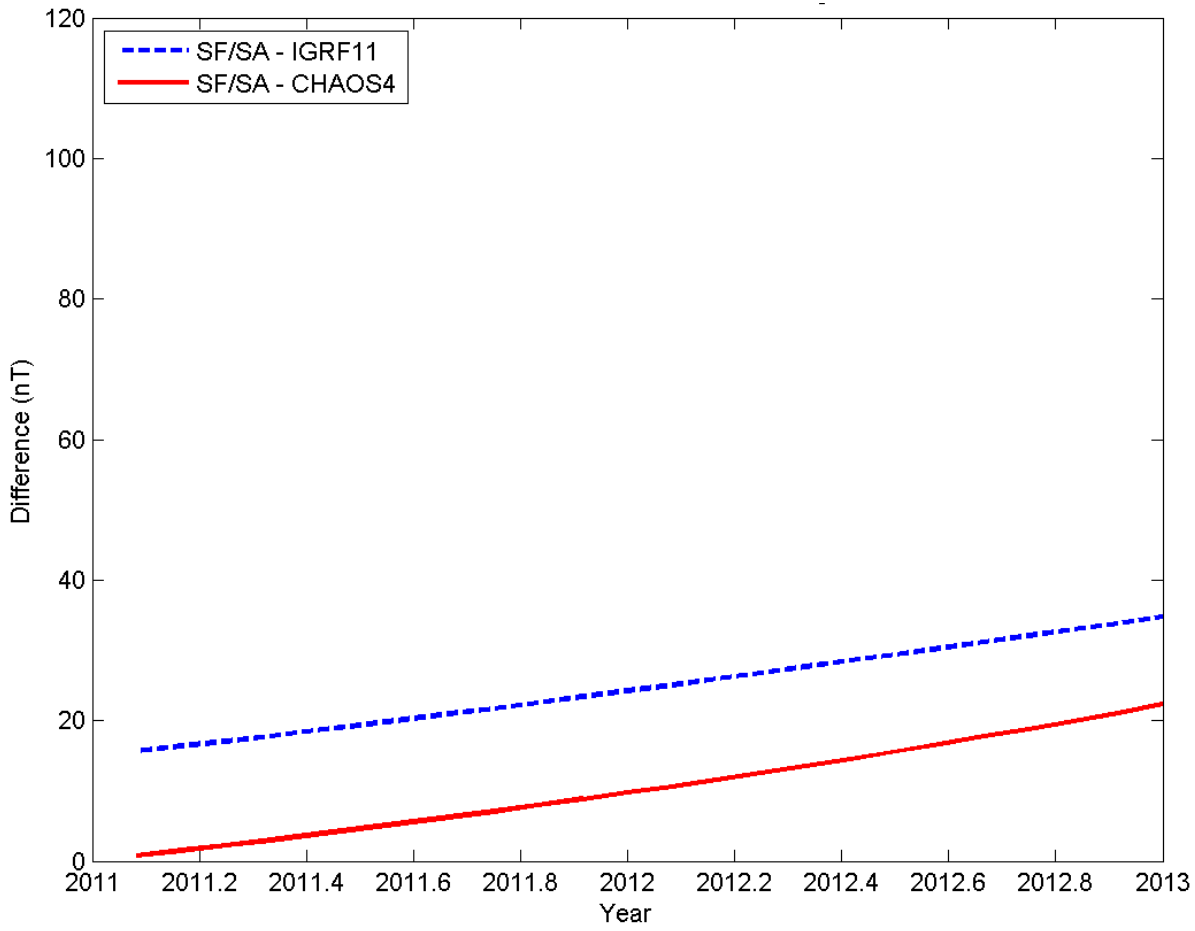
Global field models

- **IGRF-11**: International Geomagnetic Reference Field version 11
  - Developed by international community
  - Definitive: 1900-2005; Forecast: 2010-2015
  - Released: 2010.0
  - Linear SV

- **CHAOS-4**: CHAmp, Oersted, SAC-C
  - Includes Observatory data
  - Developed by Danish Technical University
  - Definitive: 1997-2013; no forecast
  - Released: July 2013
  - 6-Order spline SV



Prediction of flow/acceleration models



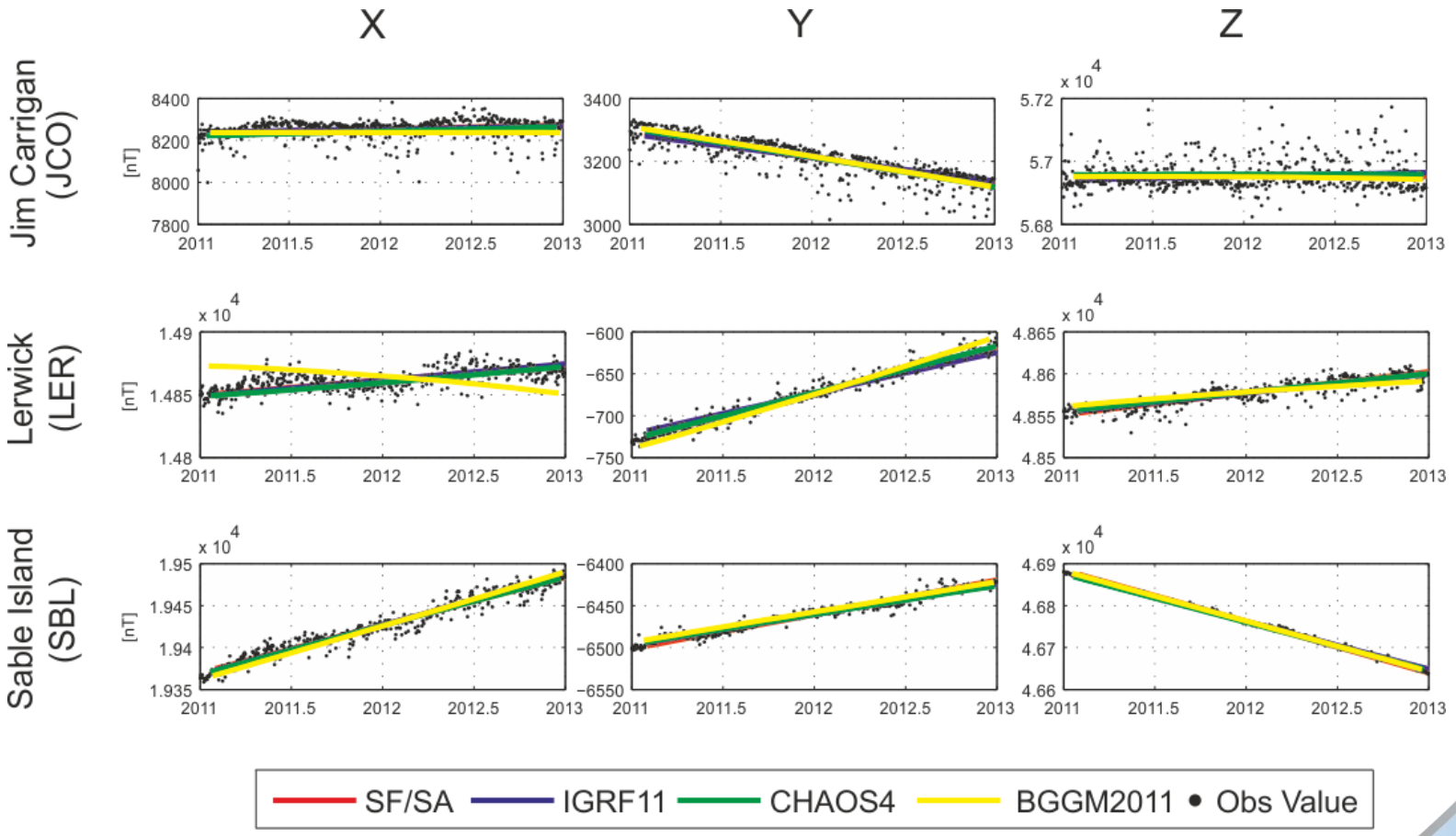
Comparison to Observatory data

- 120 observatories used (2011-2013)
  - Quiet night time hourly mean value
  - Some gaps
  - Data has a latitude variation (i.e quieter at mid-latitudes)

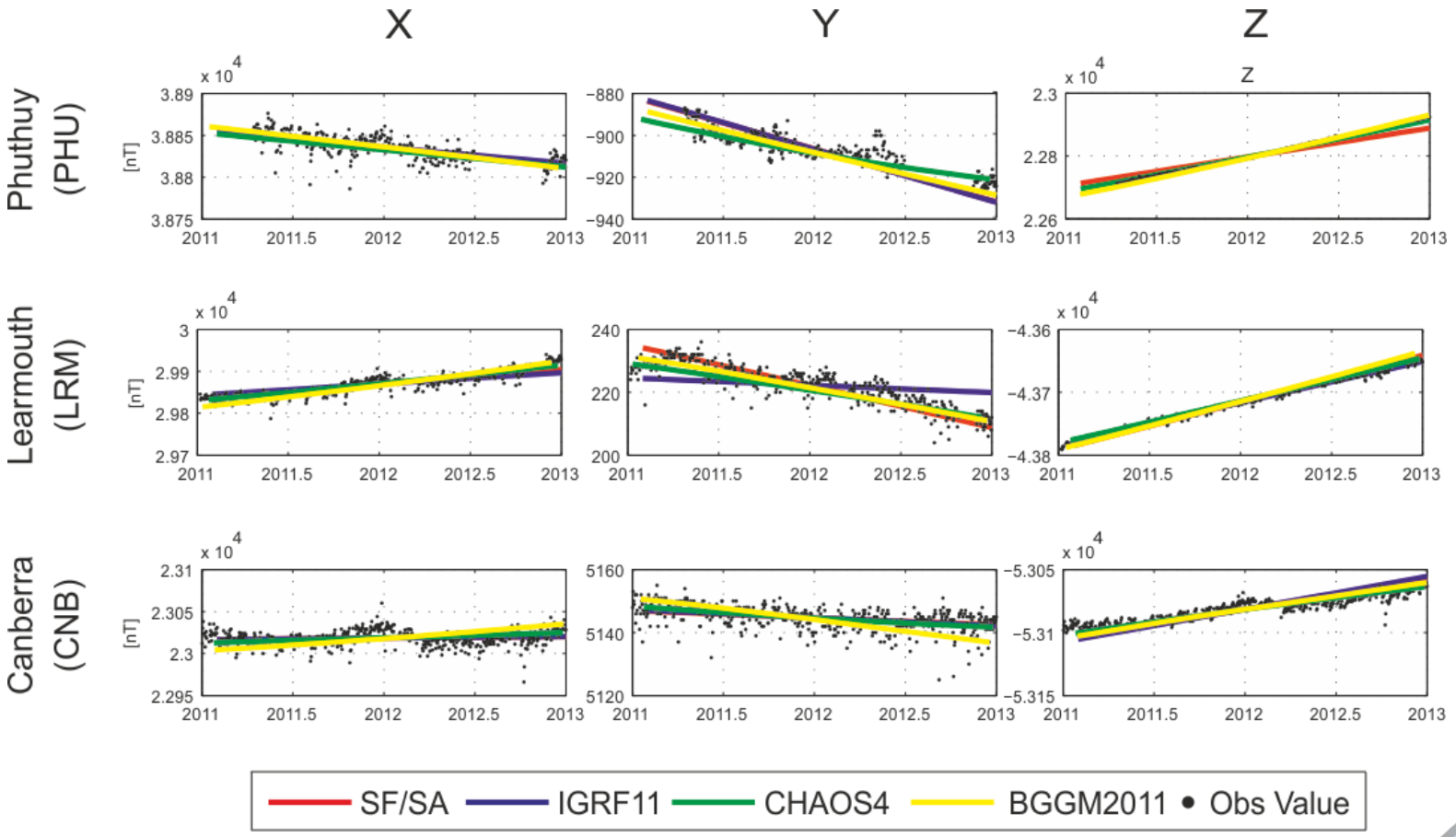
- Compute standard deviation of fit to data of:
  - SF/SA prediction
  - IGRF11 prediction
  - BGGM 2011 prediction
  - CHAOS-4 retrospective

- Northern/Southern hemisphere examples:
  - Crustal bias is removed for visualisation
  - *Slope* of line is important

Northern Hemisphere



Southern Hemisphere



Average residual to the ground observatory data

Std Dev (nT)	OBS Data	CHAOS-4	SF/SA	IGRF-11	BGGM 2011
	'Truth'	Retrospective	Predictive		
X	12.2	12.3	12.4	12.5	13.3
Y	5.3	5.9	6.0	6.6	6.5
Z	8.0	8.2	8.3	9.2	9.5

- Average misfit in nT (for two years) for 120 observatories
- Variation (std dev) of the data itself ('truth') are the residuals to a linear fit

Summary

- Difficult to draw conclusions from comparison to other global models (at the moment)

- Improvement of SF/SA over previous forecast method using observatory data comparison:
  - X ~ 7.3%
  - Y ~ 8.6%
  - Z ~ 14.4%
  - *Average ~10% improvement*

→ Flow + Acceleration improves the forecast fidelity

(Implemented into BGGM2013)

Two more things …

- ESA Swarm launches at: **1200UT 14 November 2013**
- Three satellite mission:
  - Unparalleled accuracy of magnetic field:
    - Core
    - Crust
    - External field

- Vector data will be freely available from about three months after launch though full calibration etc. will take more time

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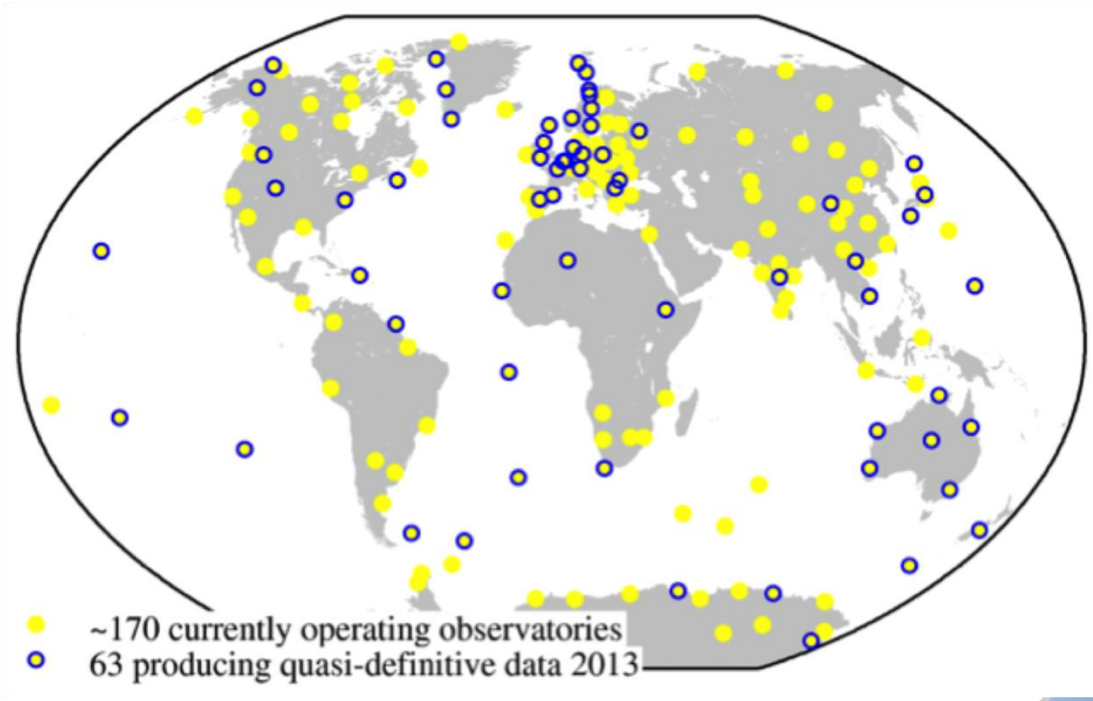
Quasi-definitive data

- In support of the Swarm mission:
  - Delivery of *quasi-definitive* data next day
  - Within 5 nT of absolute (definitive) record
  - Led by INTERMAGNET
  - Currently 63 observatories worldwide participating



Thank you for listening

Questions?