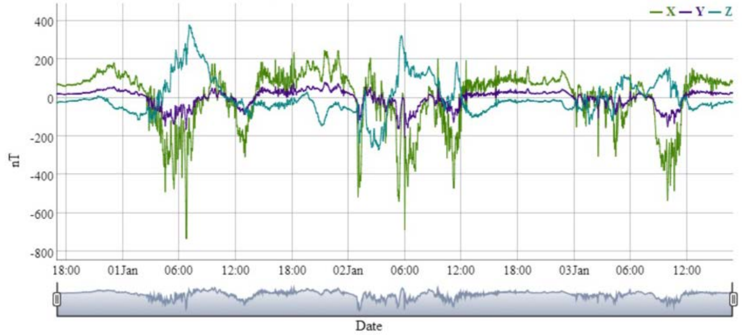
Systematic and Random Contributions to the Disturbance Field (IFR 2)



- Objectives of the study:
  - Quantify systematic disturbance field errors
  - Propose missing coefficients needed for QC
- Analysis of global geomagnetic observatory data
- Proposed changes/additions to tool codes
- Consequences in terms of ellipses of uncertainty

Stefan Maus, Manoj Nair and Bryce Carande (MagVAR),
Son Pham (ConocoPhillips) and Benny Poedjono (Schlumberger)

MagVAR

ISCWSA

Amsterdam, Oct 30th, 2014

Magnetospheric current systems

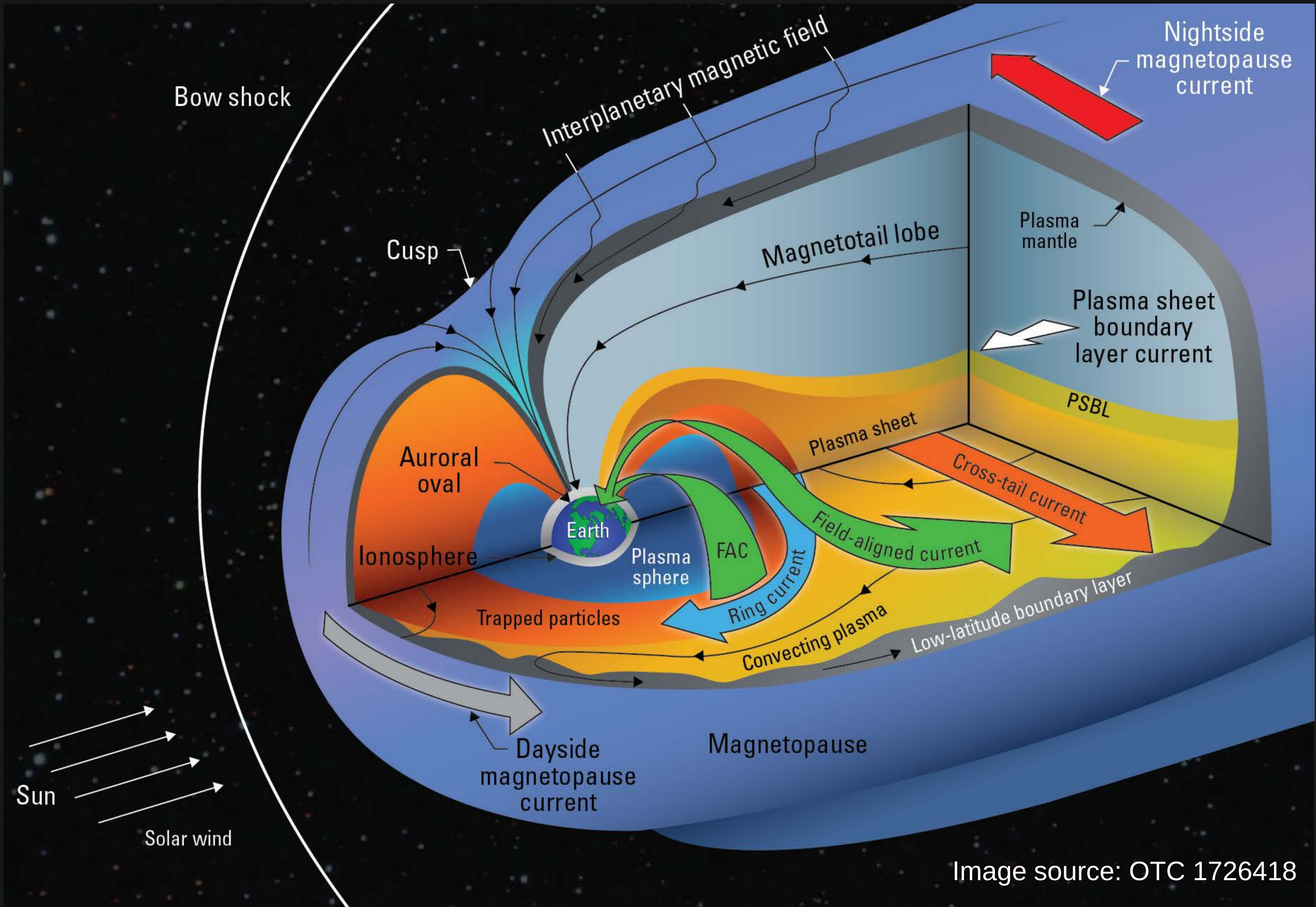


Image source: OTC 1726418

Ionospheric current systems

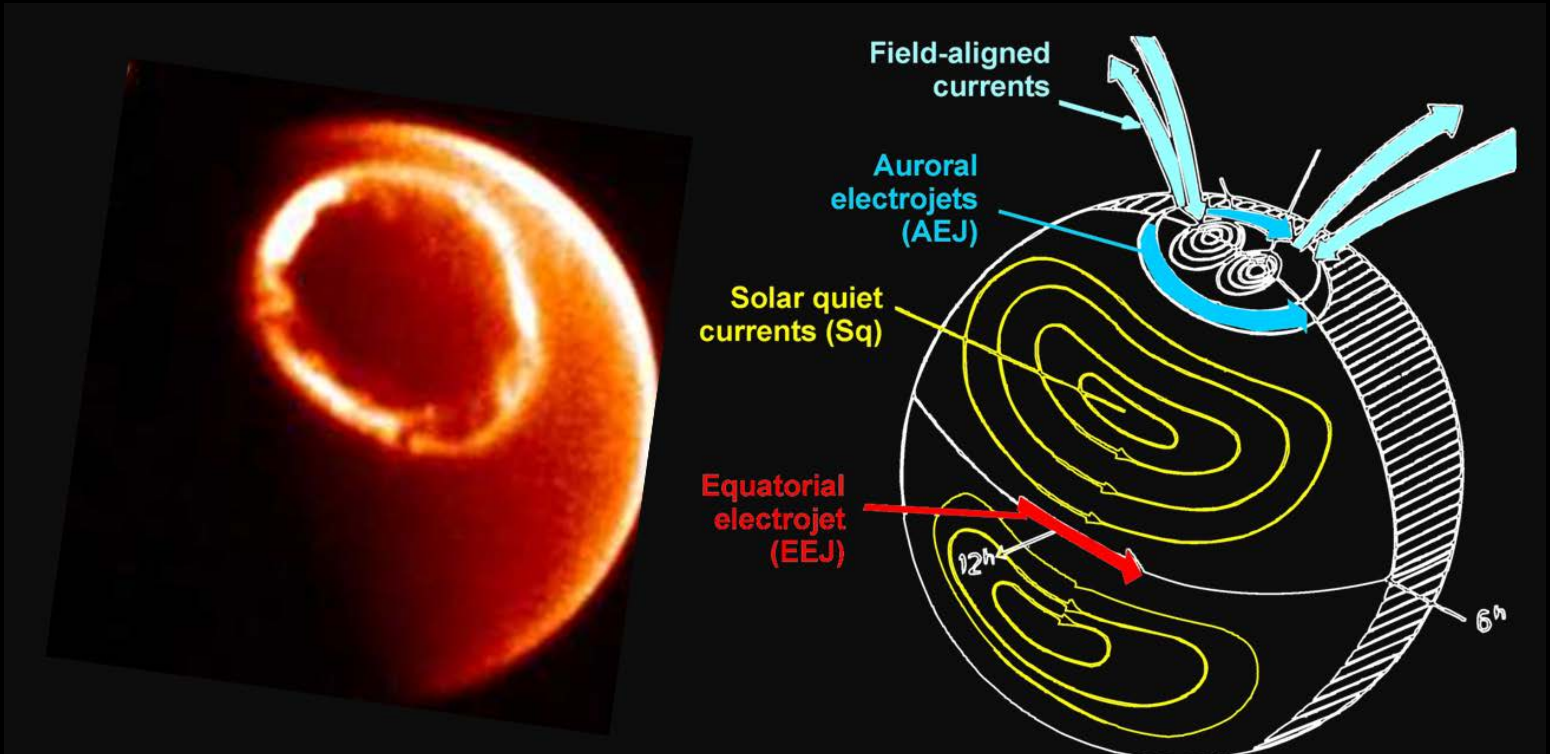
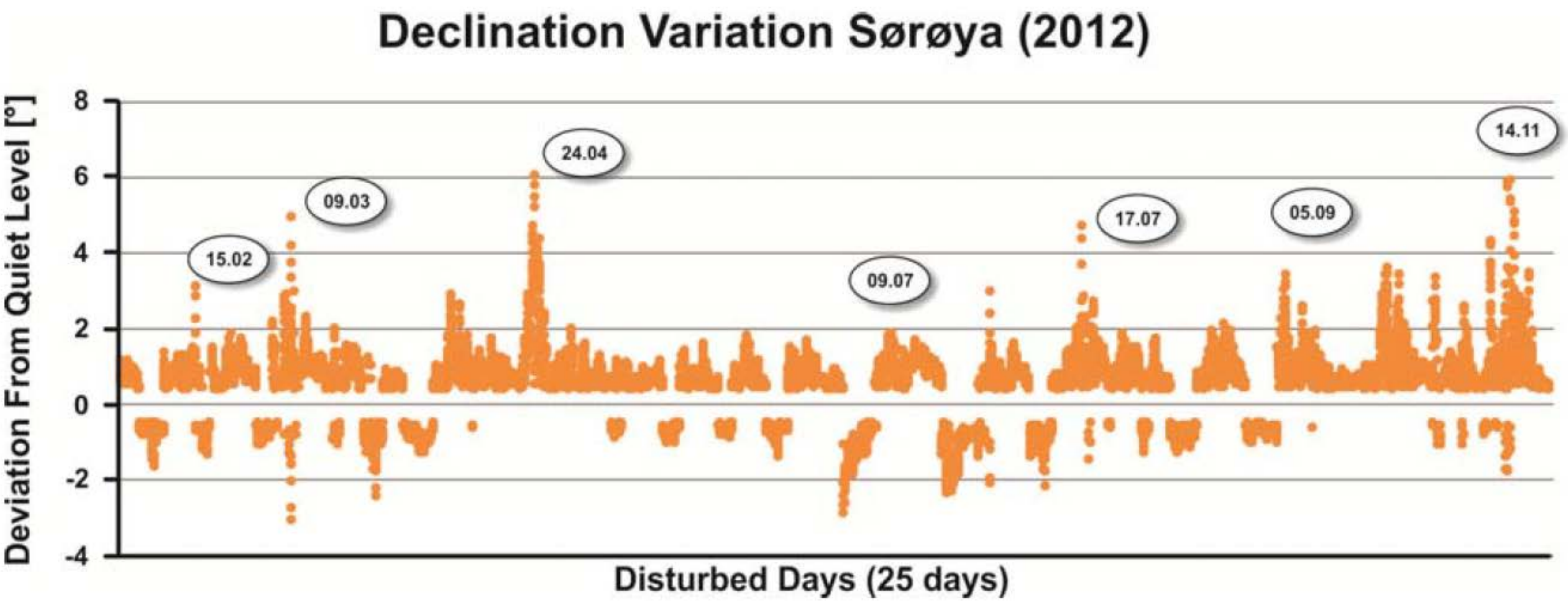


Image sources: NASA, OTC 1726418

In addition, there are induced fields:

- External magnetic fields induce electric fields in the Earth and oceans
- These generate electric currents and secondary magnetic fields
- Induced magnetic fields make up about 1/4th of the disturbance field

Motivation: Quantify systematic errors



"During a disturbed period, the magnetic declination in the Norwegian part of the Barents Sea is often affected in such a way that the mean values of the variations from quiet level have an offset of approximately 0.5º, which may result in a significant lateral position error if not corrected."

SPE 166226, Edvardsen et al

Links to relevant prior work

- ISCWSA Error Models (SPE 67616, Williamson et al., 2000)
- Confidence Limits associated with Values of the Earth's Magnetic Field used for Directional Drilling (SPE/IADC 119851, Macmillan et al, 2009)
- Quantifying the uncertainty in global geomagnetic models (ISCWSA Florence, Maus et al., 2010)
- OWSG consolidated tool codes (Steve Grindrod, Son Pham, Pete Clark, Simon McCulloch and others, 2013)
- Effective Monitoring of Auroral Electrojet Disturbances to Enable Accurate Wellbore Placement in the Arctic (OTC 1726418, Poedjono et al., 2014)
- Improving the Accuracy and Reliability of MWD Magnetic Wellbore Directional Surveying in the Barents Sea (SPE 166226, Edvardsen et al., 2014)

Relevant error model coefficients

	Declination				Total Field		Dip	
	Global		Random		Global	Random	Global	Random
	DECG	**DBHG**	**DECR**	**DBHR**	**MFIG**	**MFIR**	**MDIG**	**MDIR**
MWD								
Present value	0.36°	5000 °nT			130 nT		0.20°	
MWD+IFR1								
Present value	0.15°	1500 °nT	0.10°	1500 °nT	50 nT		0.10°	
MWD+IFR2								
Present value	0.15°	1500 °nT	0.05°	750 °nT	50 nT		0.10°	

To be verified this study

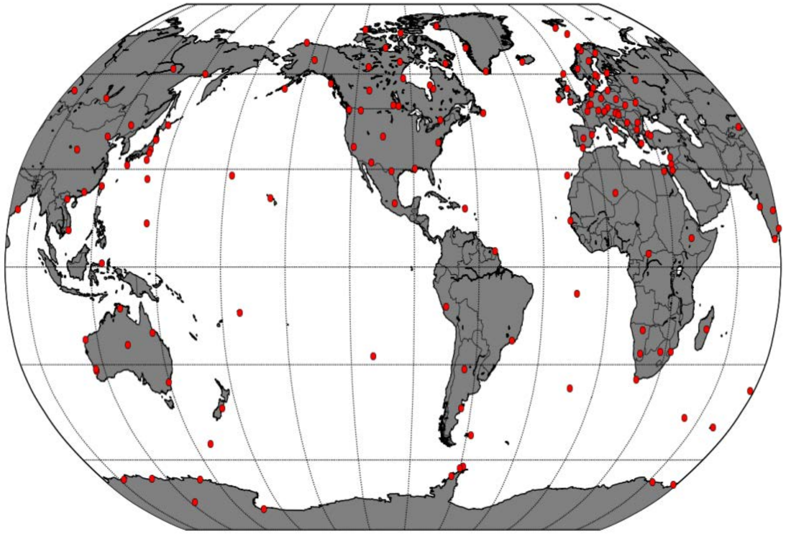
Missing or incomplete values

Study outline

- Objective: Quantify random and systematic errors
- Method
  - Use global data set of geomagnetic observatories
  - Simulate drilling of numerous lateral sections
  - Obtain statistics for azimuth error
    - Split into random and systematic azimuth error
- Results
  - Random and systematic errors for Dec, Dip, Btotal
  - Geomagnetic Storms
  - How systematic errors depend on drilling duration

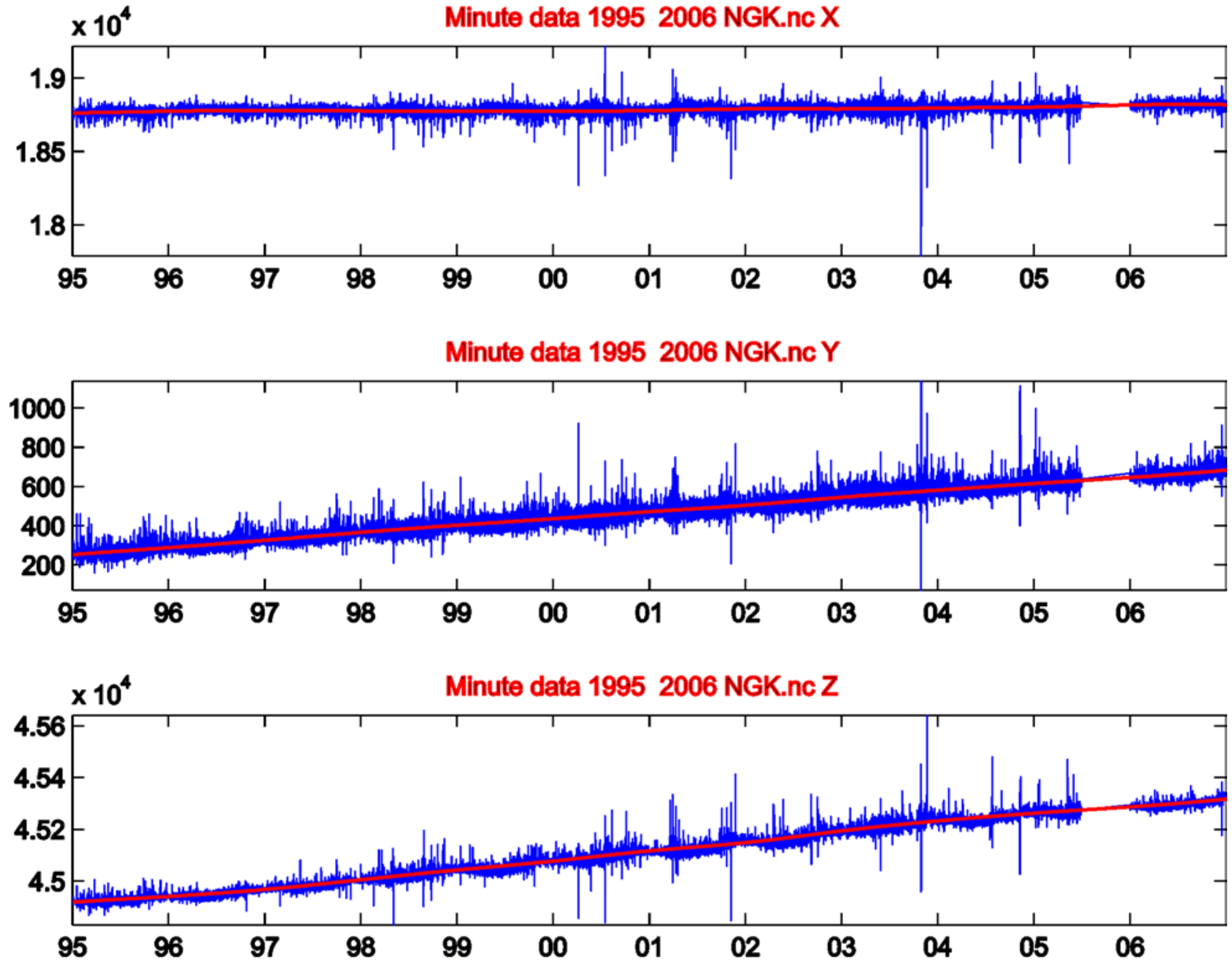
Input data

Data set = worldwide magnetic observatories:



- Used observatories as pseudo-drilling locations
- Date range 1995-2006, covering full 11 year solar cycle
- Results also subdivided by latitude and geomagnetic activity:
  - High latitudes (lat > 60˚)
  - Low- and Mid-latitudes (lat < 60˚)
  - Geomagnetic Storms (K_P > 6)

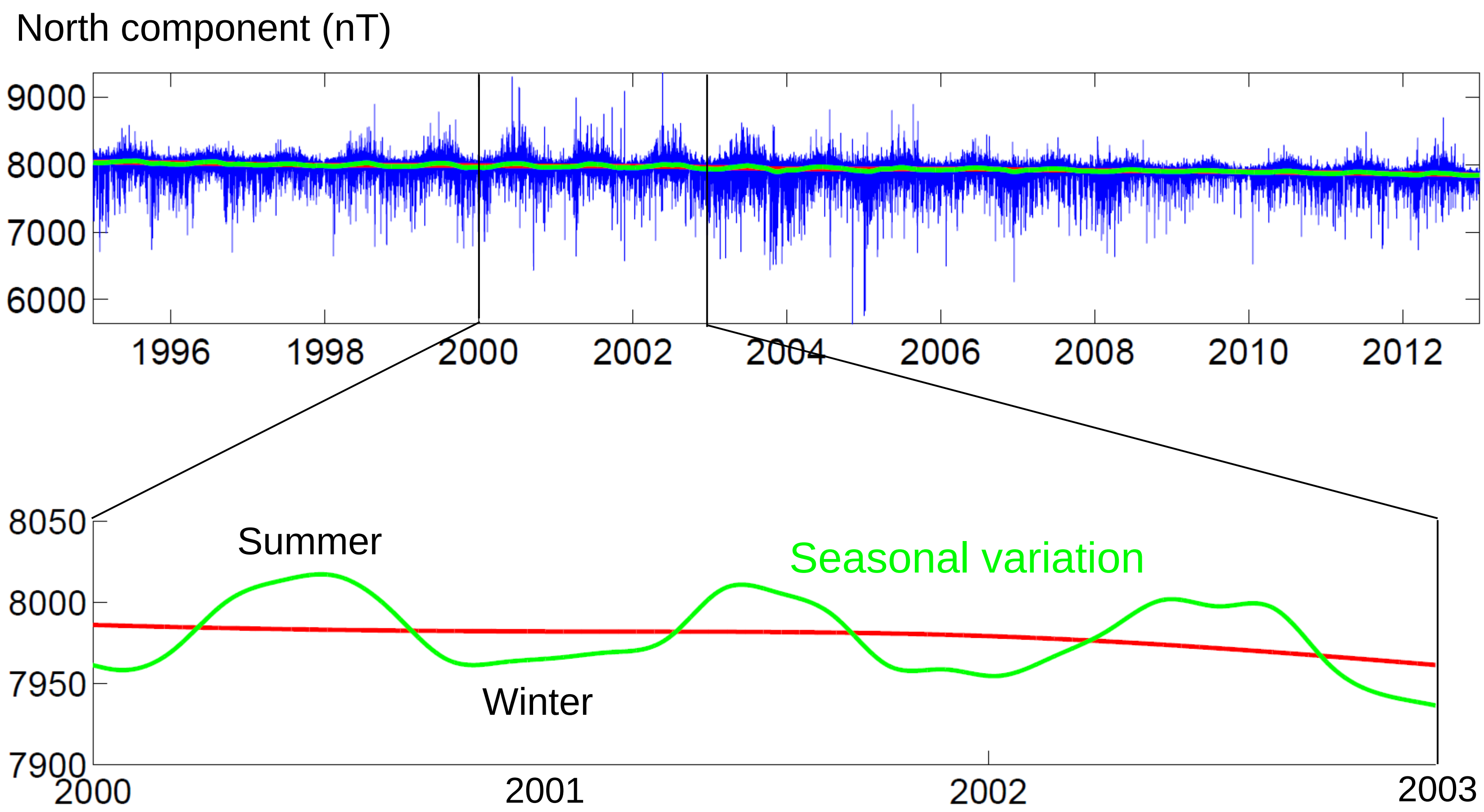
Disturbance field separation, example Niemegk



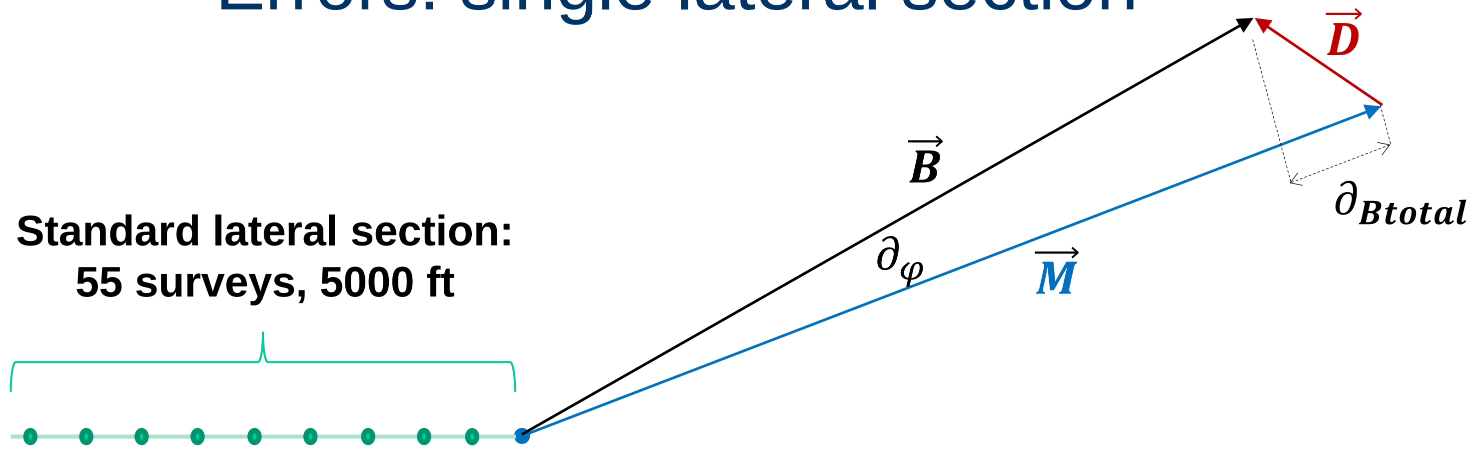
Subtracted steady background field from measurements

Spline with knot separation of 1 year to preserve annual variation

Seasonal disturbance field variation at HRN (Hornsund 15.55°E, 77.0°N)

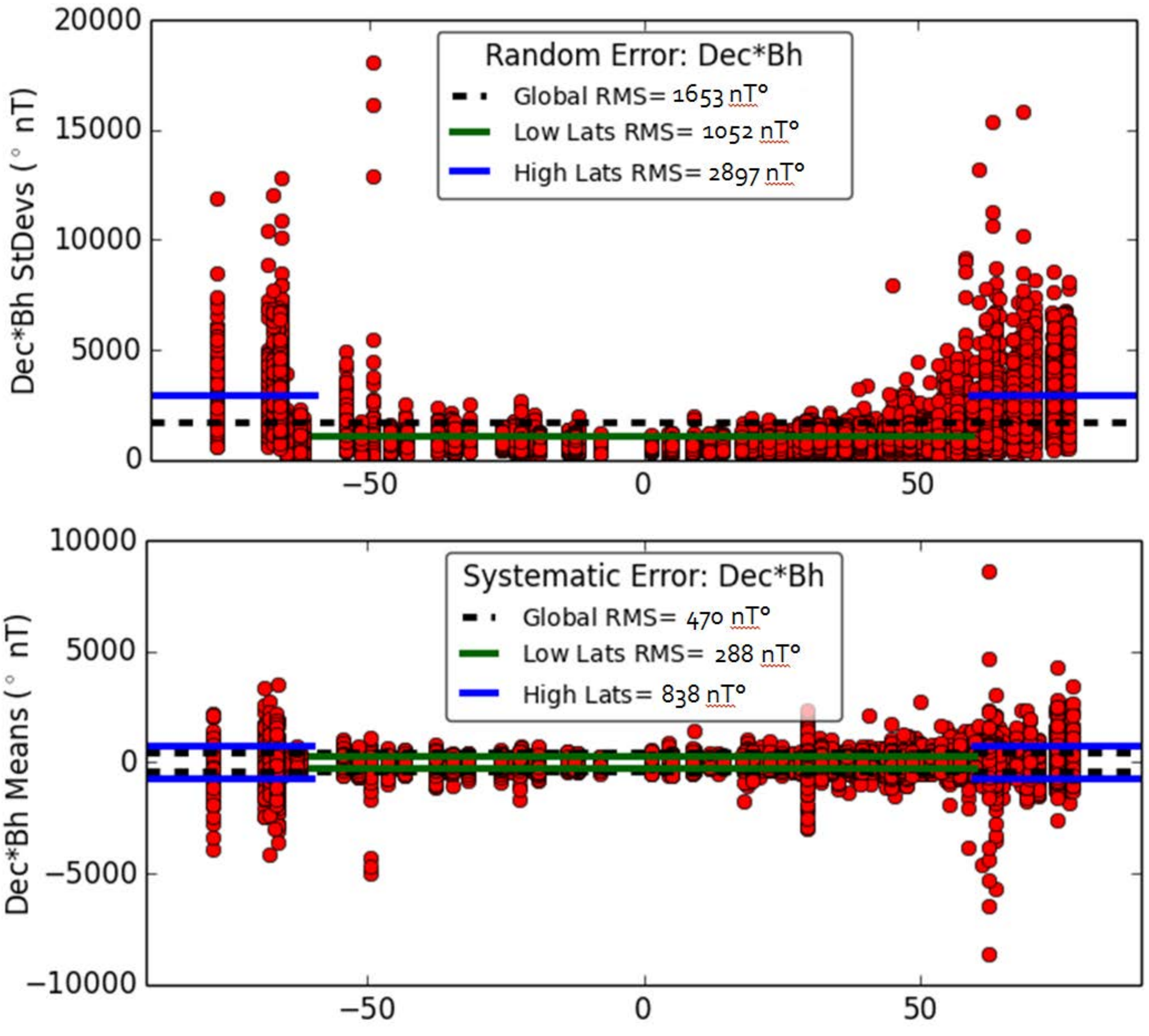


Errors: single lateral section

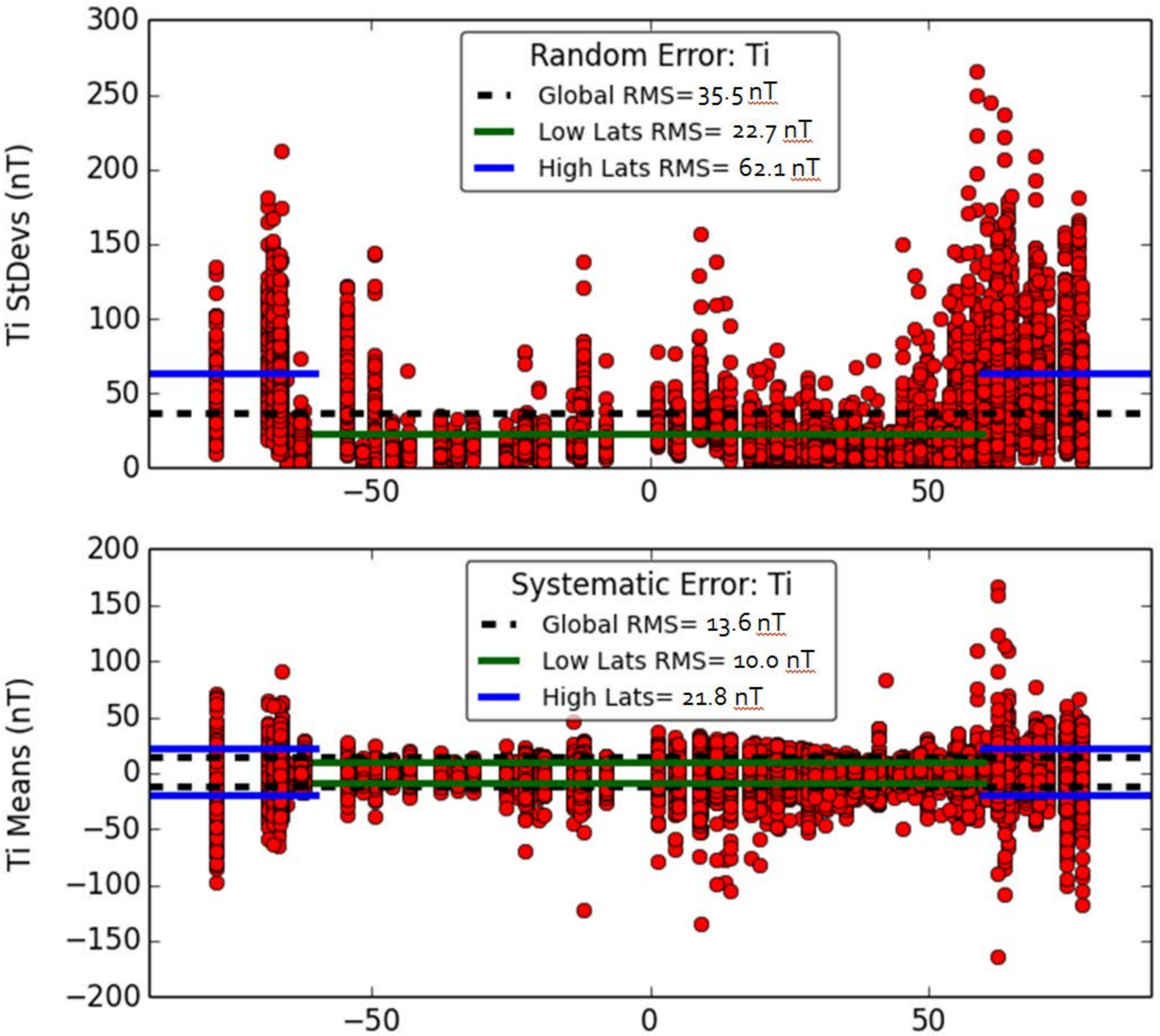


- Randomly choose 100 starting times at each observatory
- Drill 5000 ft lateral section (55 surveys @ 90 ft intervals)
- Assume 90 minutes between surveys
- From observatory measurements
  → Disturbance Declination, Dip and Btotal for each survey
- Per well errors:
  - Per well random error = $St.Dev(\partial)_{all\ surveys}$
  - Per well systematic error = $Mean(\partial)_{all\ surveys}$
- Compute global Root-Mean-Square values
  - Global random error = RMS(random errors of wells)
  - Global systematic error = RMS(systematic errors of wells)

Declination using $Dec \times B_H$

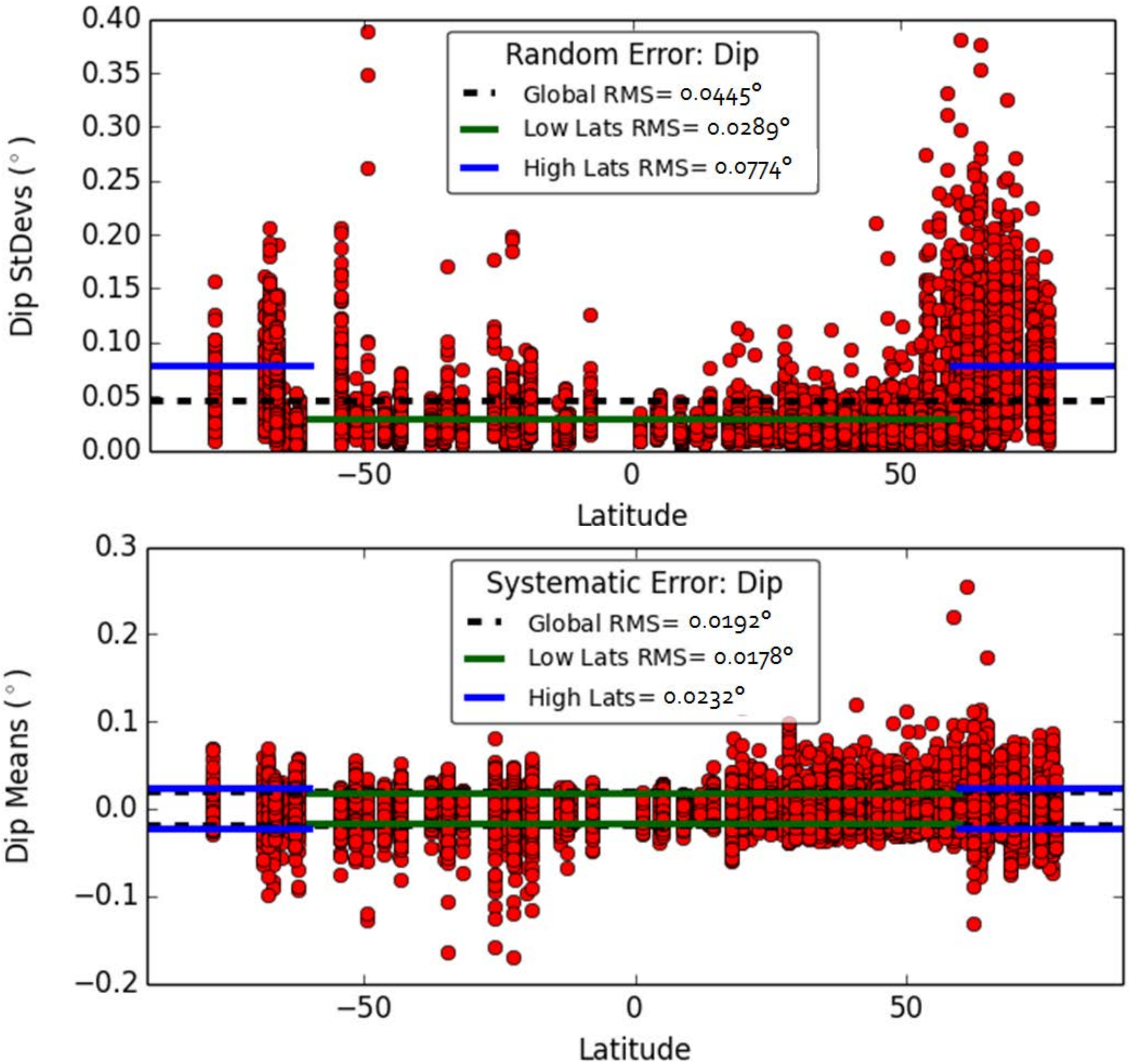


Total Field

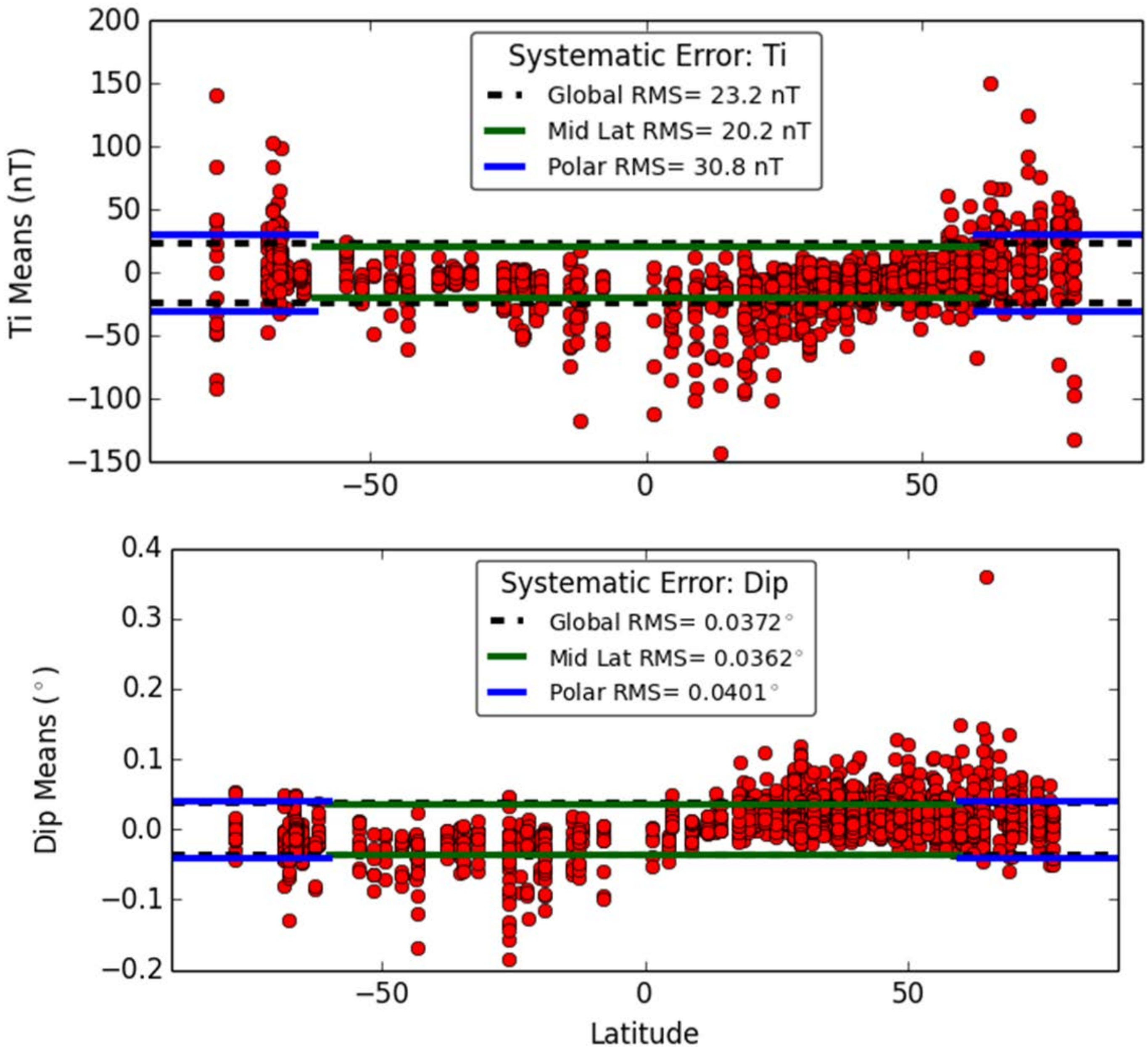


Random Error: Ti
Global RMS= 35.5 nT
Low Lats RMS= 22.7 nT
High Lats RMS= 62.1 nT
Ti StDevs (nT)
300
250
200
150
100
50
0
−50
0
50
Systematic Error: Ti
Global RMS= 13.6 nT
Low Lats RMS= 10.0 nT
High Lats= 21.8 nT
Ti Means (nT)
200
150
100
50
0
−50
−100
−150
−200
−50
0
50

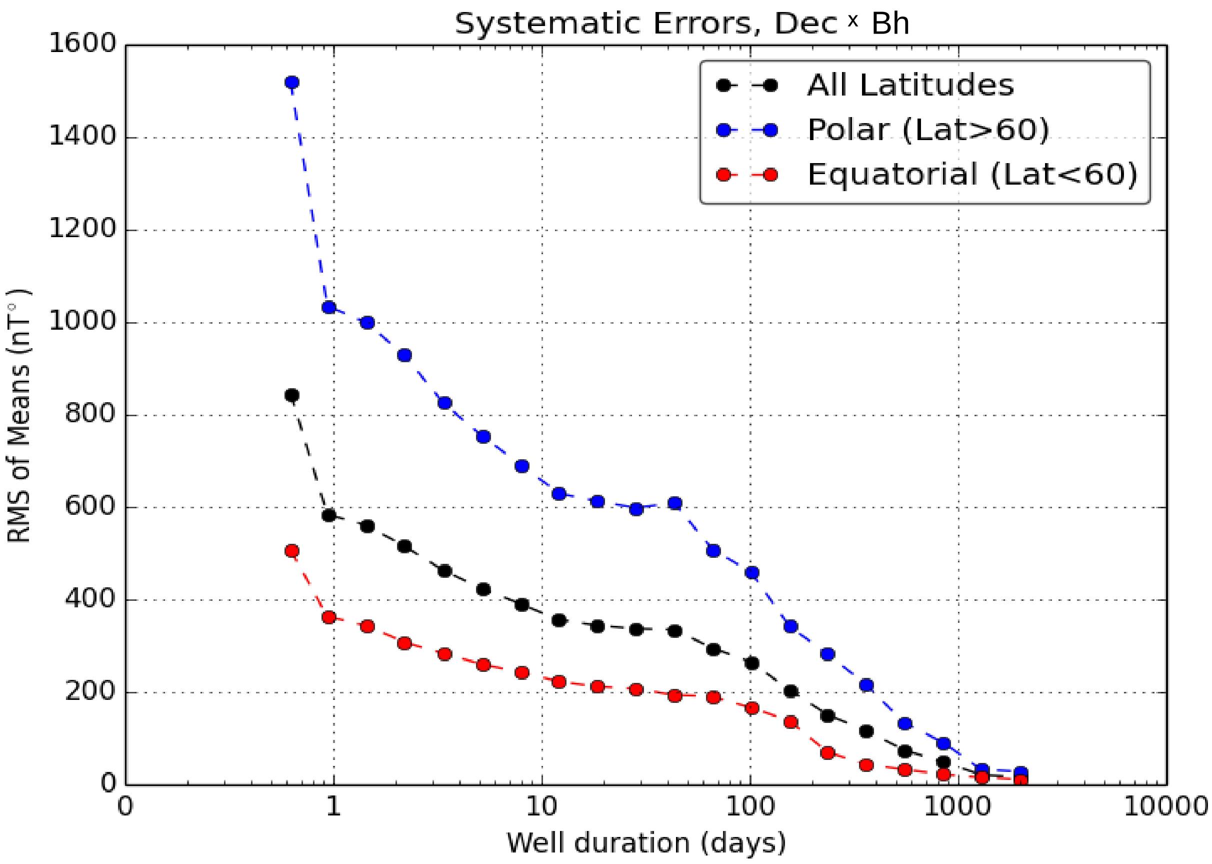
Dip


Random Error: Dip
Global RMS= 0.0445°
Low Lats RMS= 0.0289°
High Lats RMS= 0.0774°
Dip StDevs (°)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−50
0
50
Latitude
Systematic Error: Dip
Global RMS= 0.0192°
Low Lats RMS= 0.0178°
High Lats= 0.0232°
Dip Means (°)
0.3
0.2
0.1
0.0
−0.1
−0.2
−50
0
50
Latitude

Systematic error during magnetically disturbed conditions (Kp ≥ 6 any time during drilling)



Effect of drilling duration



- Over long durations, the disturbance field averages to zero
- However, the decay is very gradual

  → Significant systematic error even for long drilling durations

Summary of results

Values used for error model shown in red

		Btotal (nT)	Dip (°)	Dec*B_H (°nT)	Dec (°)
Global	Random	35.5 ± 0.10	0.045 ± 0.0001	1653 ± 5	
	Systematic	13.6 ± 0.04	0.019 ± 0.0001	470 ± 4	
High lat	Random	**62.1 ± 0.15**	**0.078 ± 0.0002**	**2897 ± 13**	
	Systematic	**21.8 ± 0.11**	**0.023 ± 0.0002**	**838 ± 12**	
Low lat	Random	22.7 ± 0.11	0.029 ± 0.0002	1052 ± 3	**0.053***
	Systematic	10.0 ± 0.04	0.018 ± 0.0001	288 ± 2	**0.014***

*Converted assuming average Bh = 20,000 nT

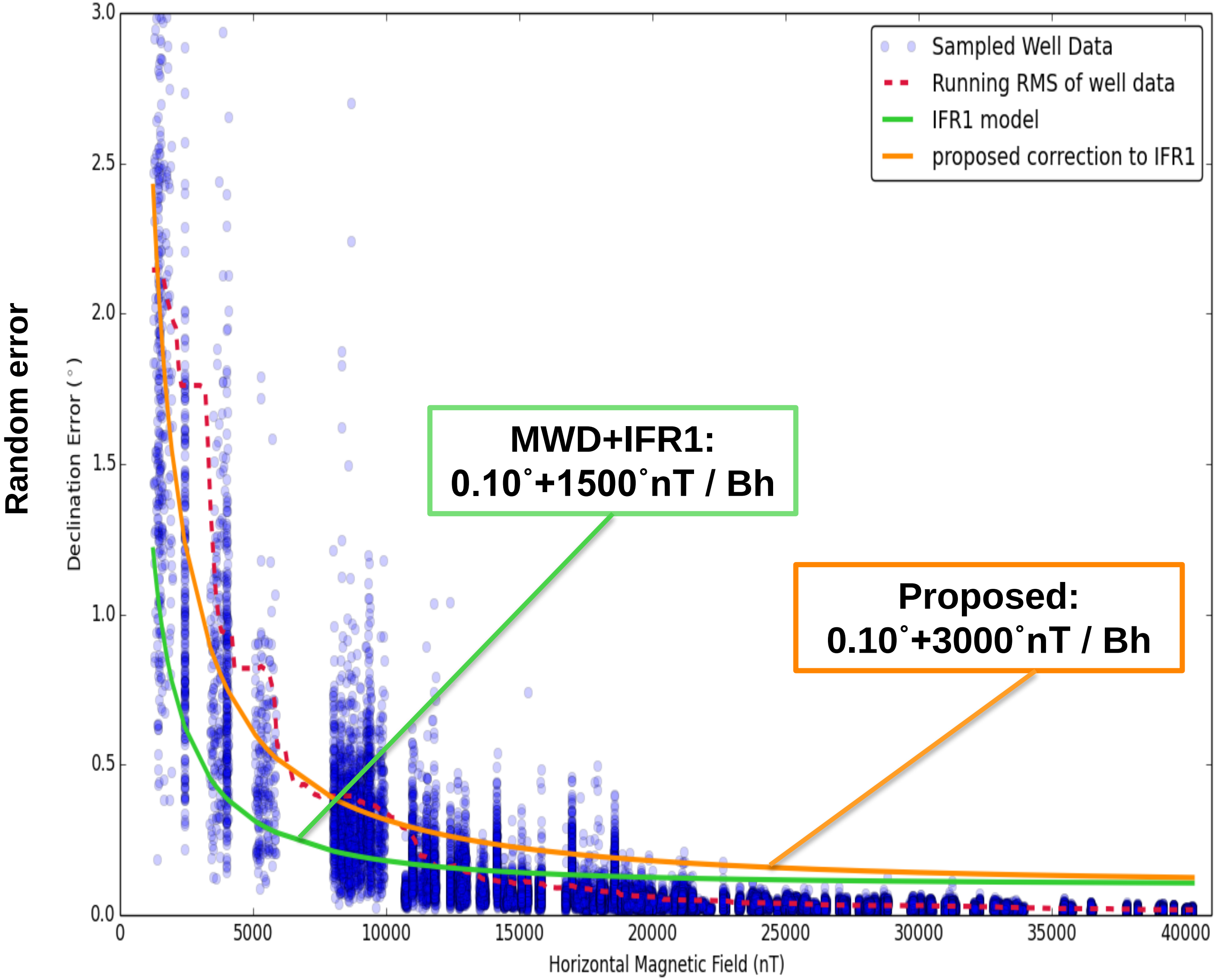
Relevant error model coefficients

	Declination				Total Field		Dip	
	Global		Random		Global	Random	Global	Random
	DECG	DBHG	DECR	DBHR	MFIG	MFIR	MDIG	MDIR
MWD								
Present value	0.36°	5000 °nT			130 nT		0.20°	
MWD+IFR1								
Present value	0.15°	1500 °nT	0.10°	1500 °nT	50 nT		0.10°	
Disturbance field only	0.01°	840 °nT	0.05°	2900 °nT				
Recommended								
MWD+IFR2								
Present value	0.15°	1500 °nT	0.05°	750 °nT	50 nT		0.10°	

To be verified this study

Missing or incomplete values

Current tool code underestimates random error



Relevant error model coefficients

	Declination				Total Field		Dip	
	Global		Random		Global	Random	Global	Random
	DECG	**DBHG**	**DECR**	**DBHR**	**MFIG**	**MFIR**	**MDIG**	**MDIR**
MWD								
Present value	0.36°	5000 °nT			130 nT		0.20°	
MWD+IFR1								
Present value	0.15°	1500 °nT	0.10°	1500 °nT	50 nT		0.10°	
Disturbance field only	0.01°	840 °nT	0.05°	2900 °nT				
Recommended	0.15°	1500 °nT	0.10°	**3000 °nT**				
MWD+IFR2								
Present value	0.15°	1500 °nT	0.05°	750 °nT	50 nT		0.10°	

Red = increased value

Residual error (1σ) after IFR2 correction

for magnetically disturbed conditions (Kp ≥ 6)

- Stations used: High latitude Observatories, Canadian Carisma array and Scandinavian Image array
- Assuming only 1 nearby station is used for the IFR2 correction

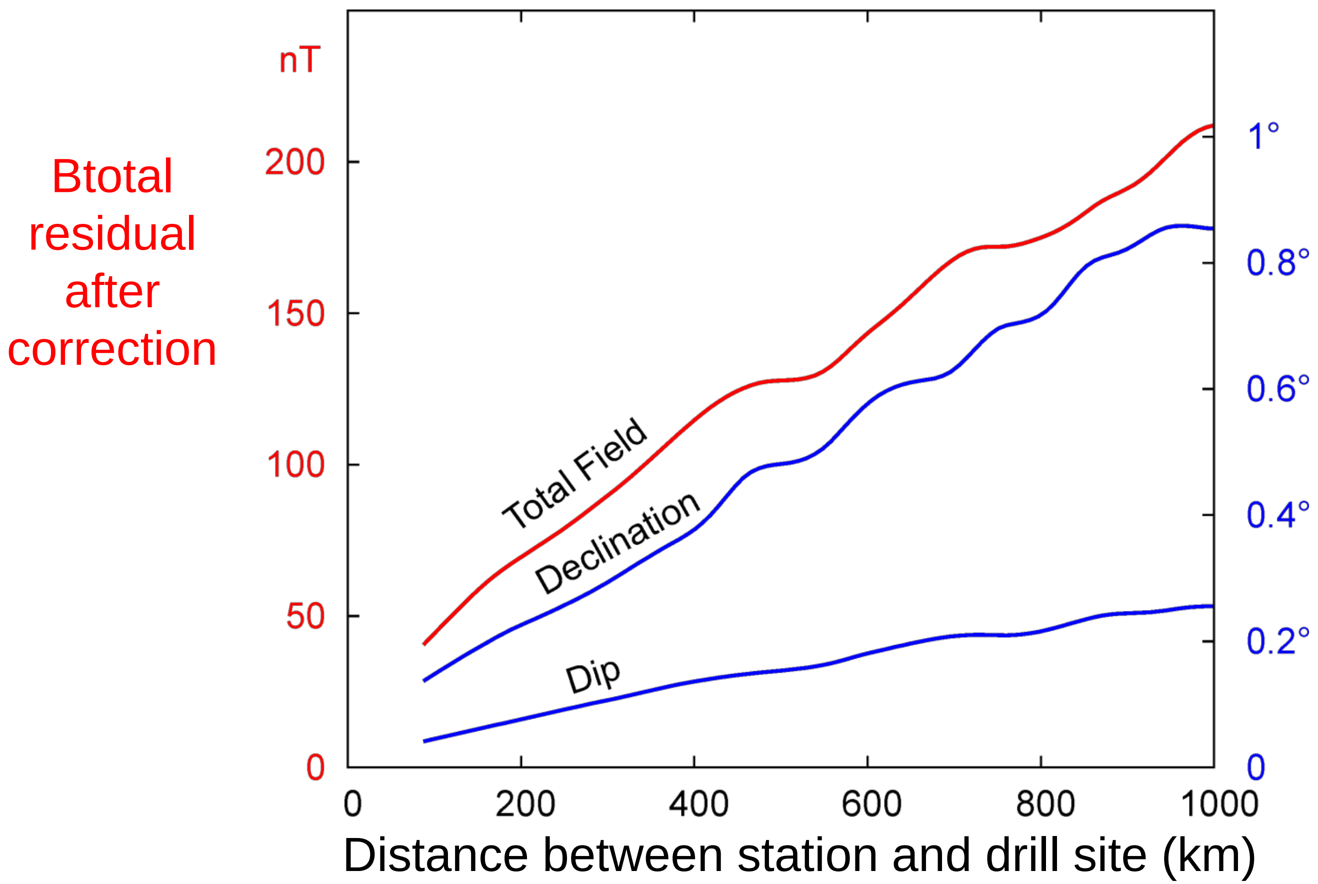


Image source: OTC 1726418

Residual error (1σ) after IFR2 correction

all magnetic conditions

Assuming only 1 nearby station is used for the IFR2 correction:

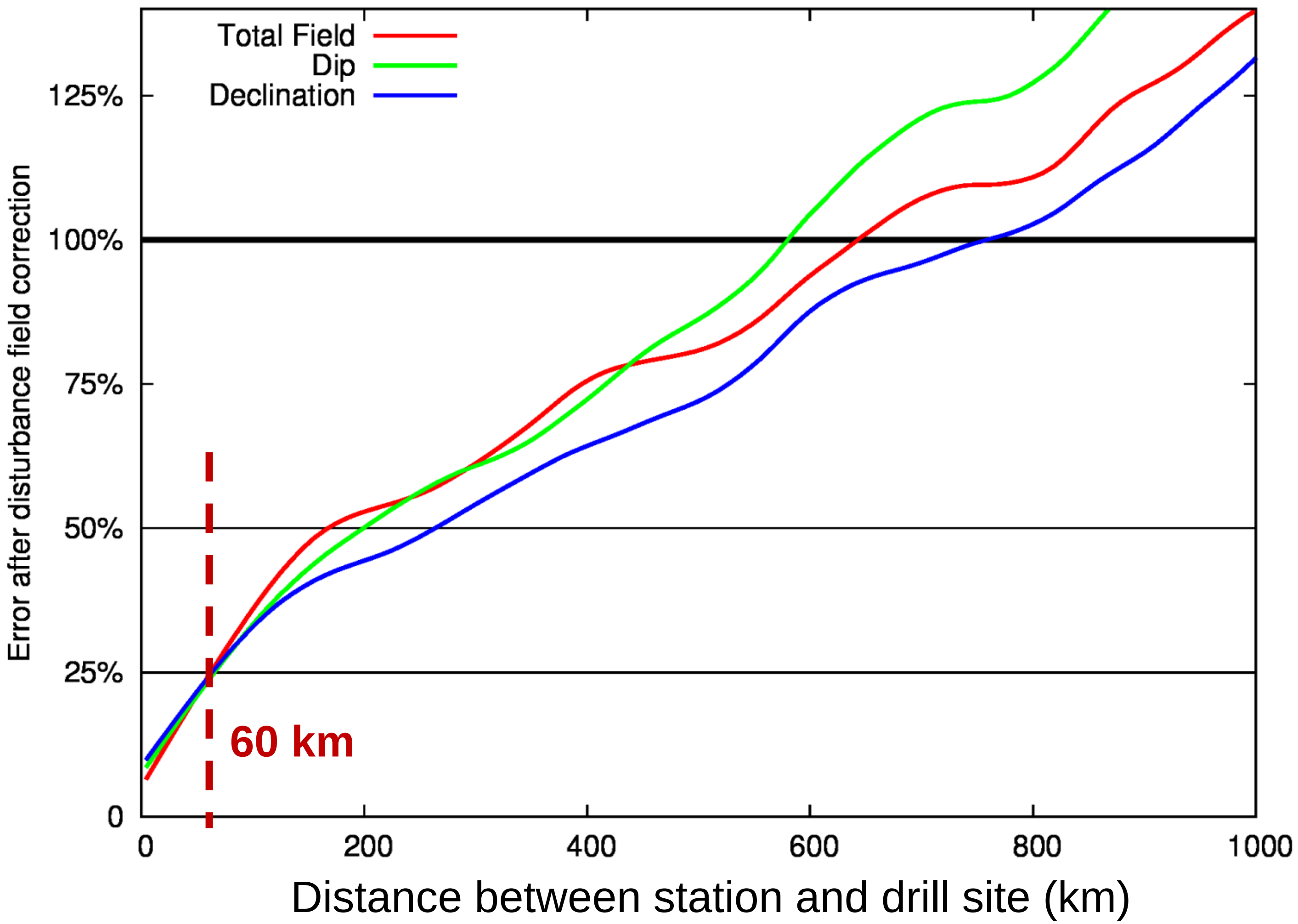


Image source: OTC 1726418

Relevant error model coefficients

	Declination				Total Field		Dip	
	Global		Random		Global	Random	Global	Random
	DECG	**DBHG**	**DECR**	**DBHR**	**MFIG**	**MFIR**	**MDIG**	**MDIR**
MWD								
Present value	0.36°	5000 °nT			130 nT		0.20°	
MWD+IFR1								
Present value	0.15°	1500 °nT	0.10°	1500 °nT	50 nT		0.10°	
Disturbance field only	0.01°	840 °nT	0.05°	2900 °nT				
Recommended	0.15°	1500 °nT	0.10°	**3000 °nT**				
MWD+IFR2								
Present value	0.15°	1500 °nT	0.05	[illegible]	[illegible]	[illegible]	[illegible]10°	
1/4th Disturbance field	0.00°	210 °nT	0.01	[illegible]	[illegible]	[illegible]		
Recommended	0.15°	**1250 °nT**	0.05°	750 °nT				

$$\sqrt{1500^2 - 840^2 + 210^2} = 1260$$

Green = new **Blue = reduced value** **Red = increased value**

Ellipses of uncertainty: old versus new IFR2

L-shaped well with 11,000 ft lateral section, oriented southward

Location	Bh	IFR2 + MS	IFR2 + MS proposed	Change
Golf of Mexico	26,000 nT	124.4 ft	123.3 ft	-0.9%
Bakken, ND	16300 nT	154.3 ft	151.9 ft	-1.6%
Alberta	12600 nT	186.1 ft	182.8 ft	-1.7%
Alaska	9000 nT	251.6 ft	246.8 ft	-1.9%
Northern Canada	4000 nT	458.0	444.1 ft	-3.0%

- Reduction caused by reducing DBHG term from 1500 °nT to 1250 °nT
- But other error sources overshadow this term
  - →Particularly for east-west wells (not shown)

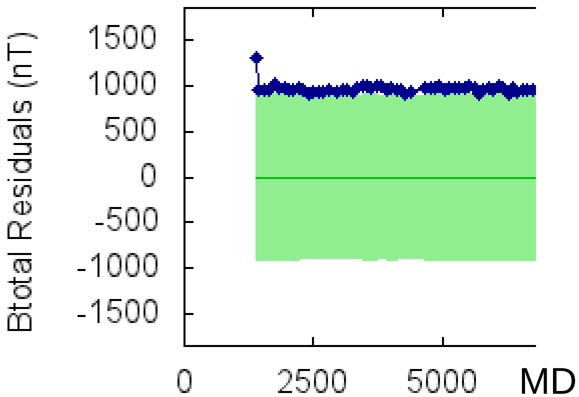
Relevant error model coefficients

	Declination				Total Field		Dip	
	Global		Random		Global	Random	Global	Random
	DECG	**DBHG**	**DECR**	**DBHR**	**MFIG**	**MFIR**	**MDIG**	**MDIR**
MWD								
Present value	0.36°	5000 °nT			130 nT		0.20°	
Disturbance field only	0.01°	840 °nT	0.05°	2900 °nT	22 nT	62 nT	0.023°	0.08°
Recommended	0.36°	5000 °nT	**0.10°**	**3000 °nT**	130 nT	**60 nT**	0.20°	**0.08°**
MWD+IFR1								
Present value	0.15°	1500 °nT	0.10°	1500 °nT	50 nT		0.10°	
Disturbance field only	0.01°	840 °nT	0.05°	2900 °nT	22 nT	62 nT	0.023°	0.08°
Recommended	0.15°	1500 °nT	0.10°	**3000 °nT**	50 nT	**60 nT**	0.10°	**0.08°**
MWD+IFR2								
Present value	0.15°	1500 °nT	0.05°	750 °nT	50 nT		0.10°	
1/4th Disturbance field	0.00°	210 °nT	0.01°	725 °nT	6 nT	15 nT	0.006°	0.02°
Recommended	0.15°	**1250 °nT**	0.05°	750 °nT	**45 nT**	**15 nT**	**0.08°**	**0.02°**

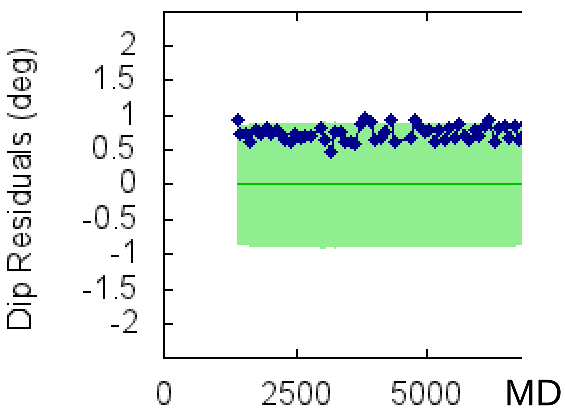
Green = new **Blue = reduced value** **Red = increased value**

Adding the missing coefficients enables QC

Raw data (MWD tool code)



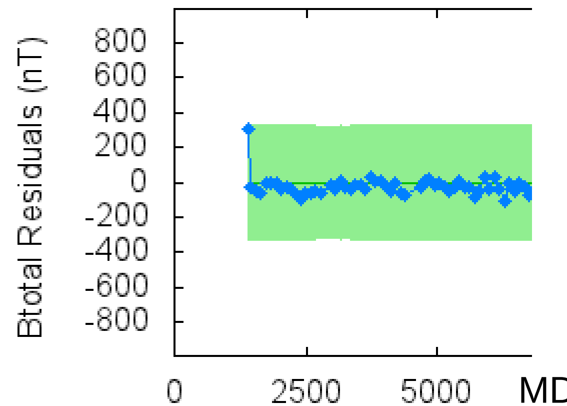
3 sigma



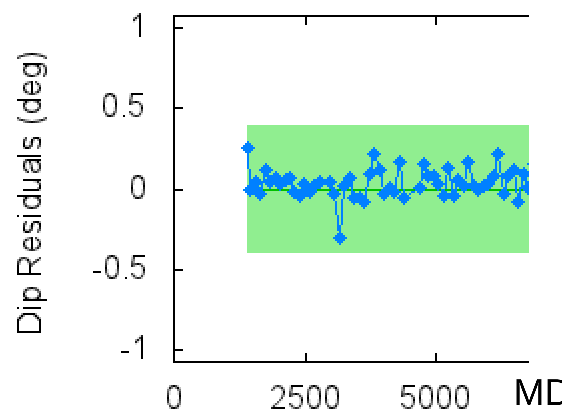
3 sigma

MSA corrected data

(MWD+IFR1+MS tool code)



3 sigma



3 sigma

Conclusions

- This study has quantified disturbance field errors
  - Random error is higher than in present tool codes
  - Systematic error ≈ 1/3rd to 1/4th of random error
    - → EOU should be reduced when applying IFR2 correction
- Add reference errors for Btotal and Dip to tool codes
  - QC thresholds can be computed from tool code
  - Enables check whether MWD tool performance is consistent with chosen tool code

Acknowledgement of observatory and variometer data providers