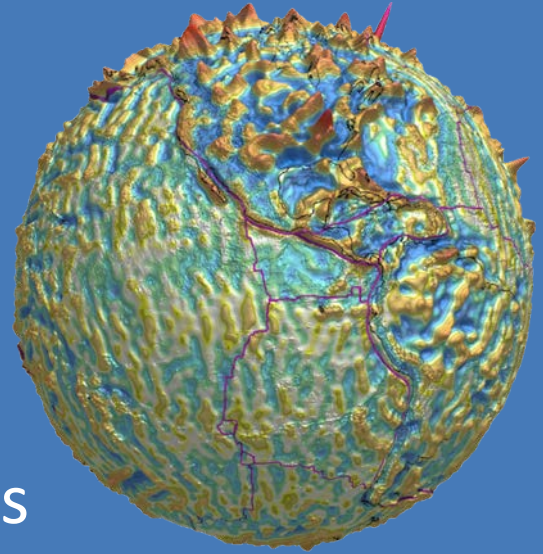


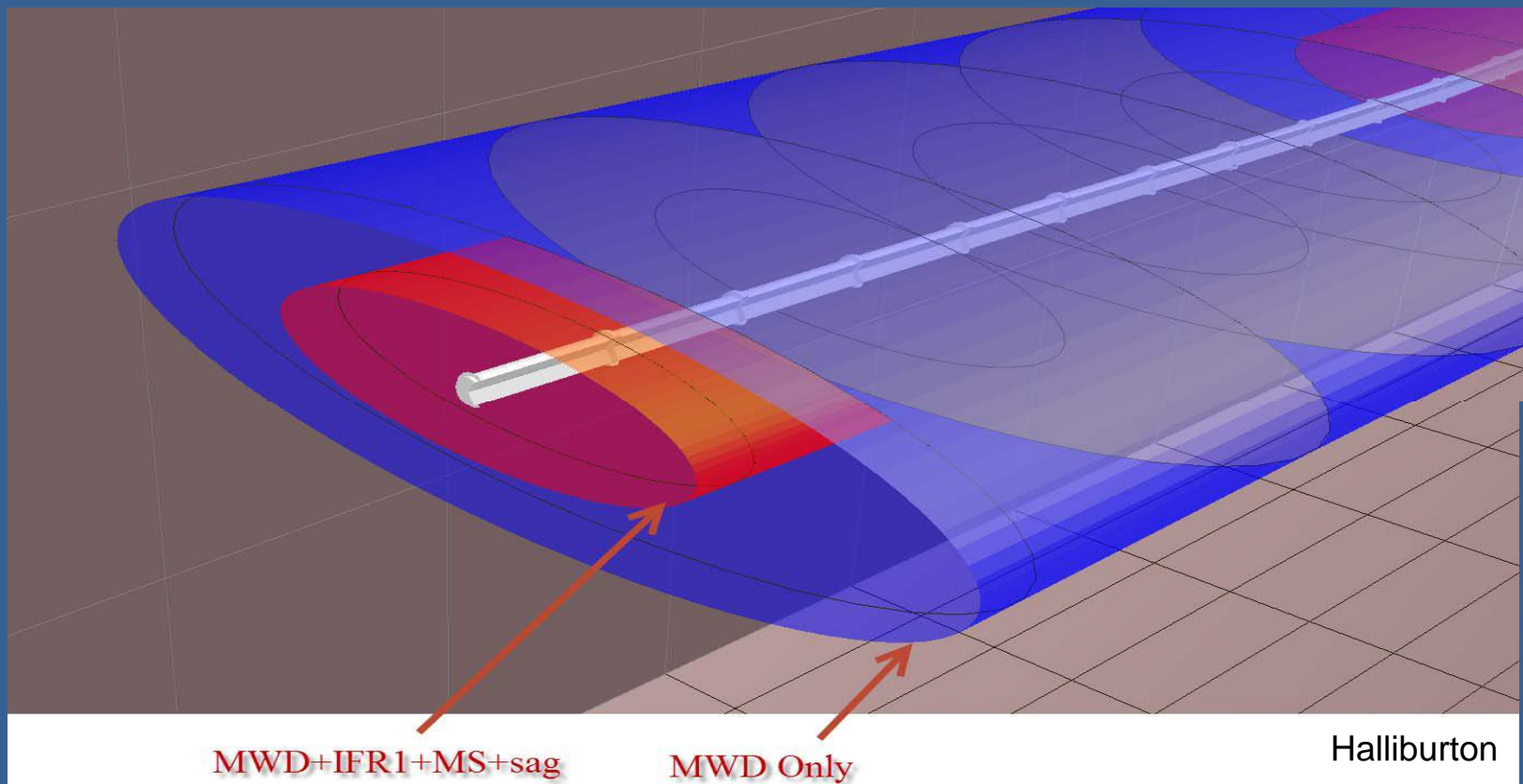
Magnetic Referencing and Survey Accuracy for Horizontal Development in the Permian



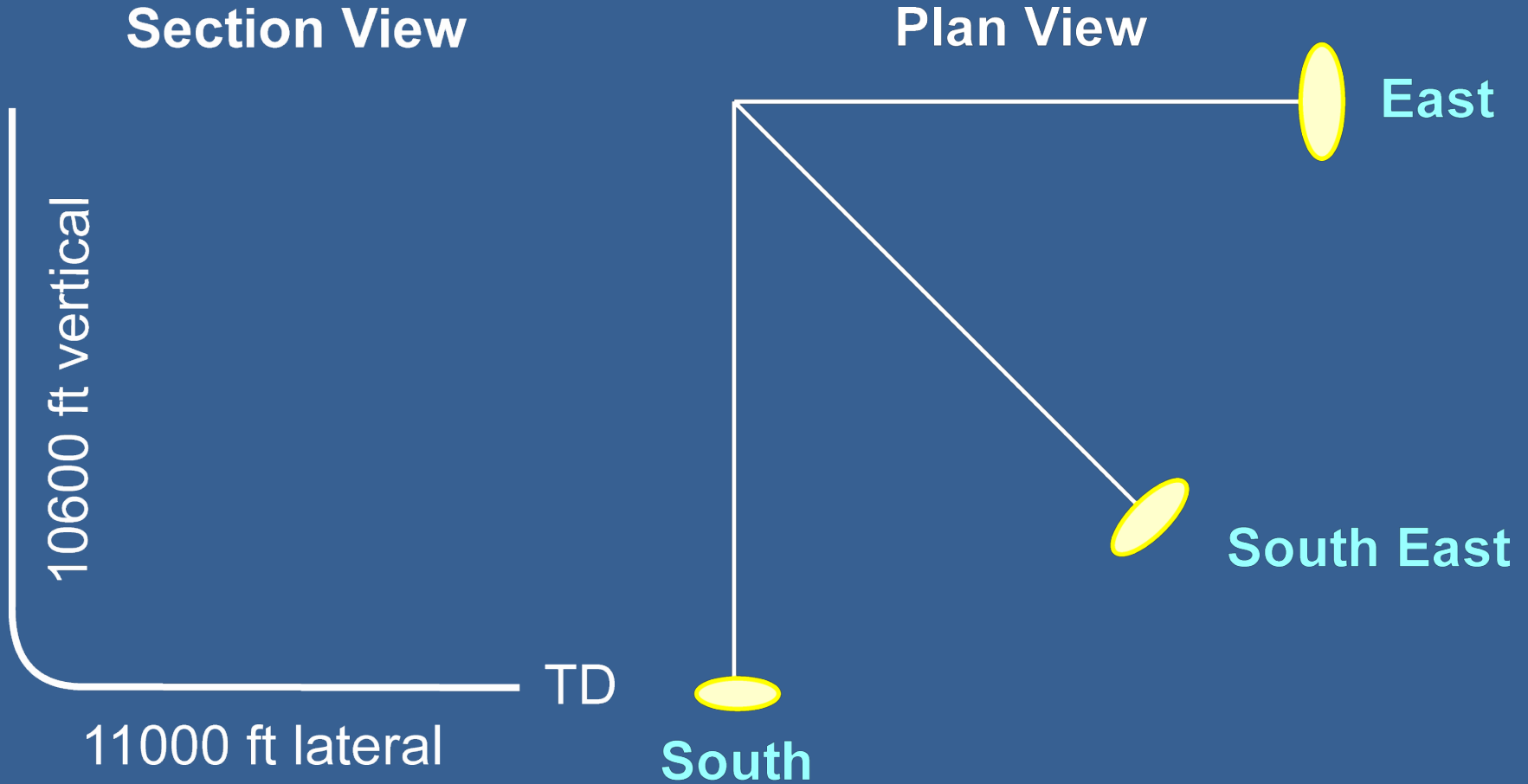
- Wellbore position uncertainty
- Global and local geomagnetic models
- Quality control and advanced corrections
 - Tool code and orientation dependent QC thresholds
 - Multi-Station Analysis (MSA)
- New OWSG tool codes for well planning and AC

Positional Uncertainty in MWD

- Largest source of lateral error: Magnetic field
- Accurate geomagnetic models and advanced corrections significantly reduce this error



Ellipses of Uncertainty Study



Uncertainties in West TX

Lateral Uncertainty at TD

Well Azim.	Lateral Length	MWD	MWD +IFR1	MWD +IFR1+MS
	(ft)	(ft)	(ft)	(ft)
E	11000	439	390 (-11%)	173 (-61%)
SE	11000	387	329 (-15%)	160 (-59%)
S	11000	259	161 (-38%)	129 (-50%)

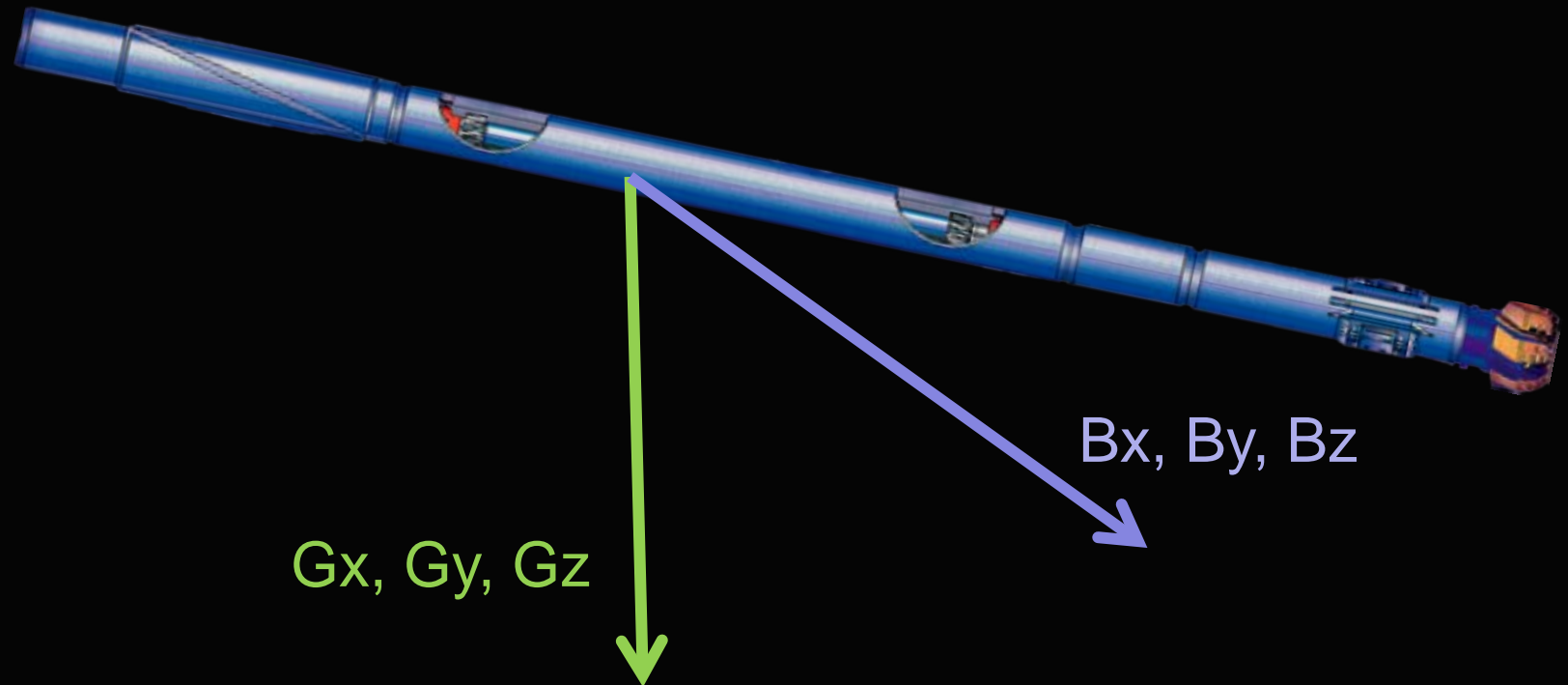
Vertical Uncertainty at TD

TVD	MWD	MWD+IFR1+SAG+MS
10600 ft	119 ft	71 ft (-40%)

3D Ellipsoids given
for 95% confidence
interval = 2.79 sigma

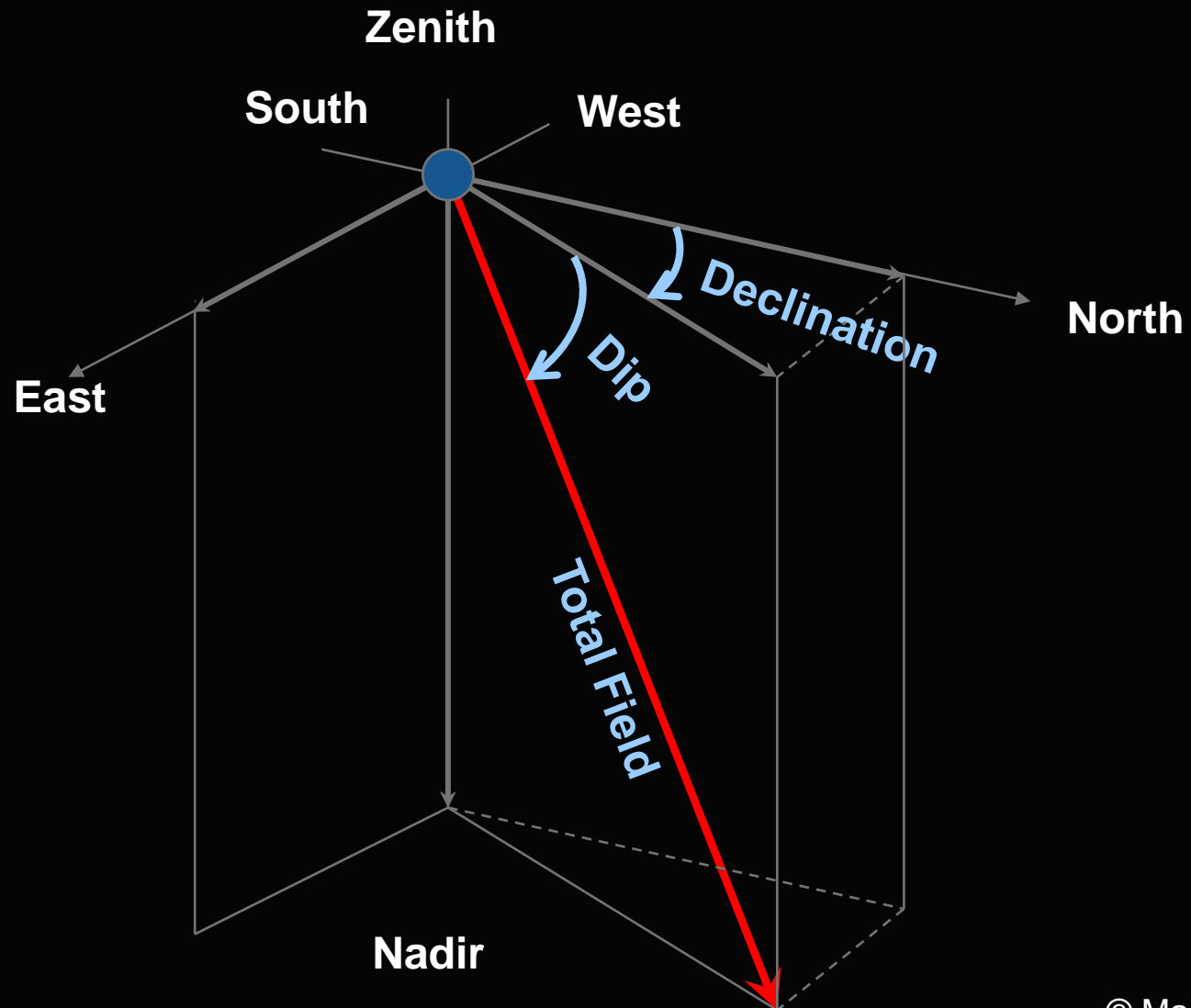
Error model:
ISCWSA OWSG

What Does the MWD Tool Measure?

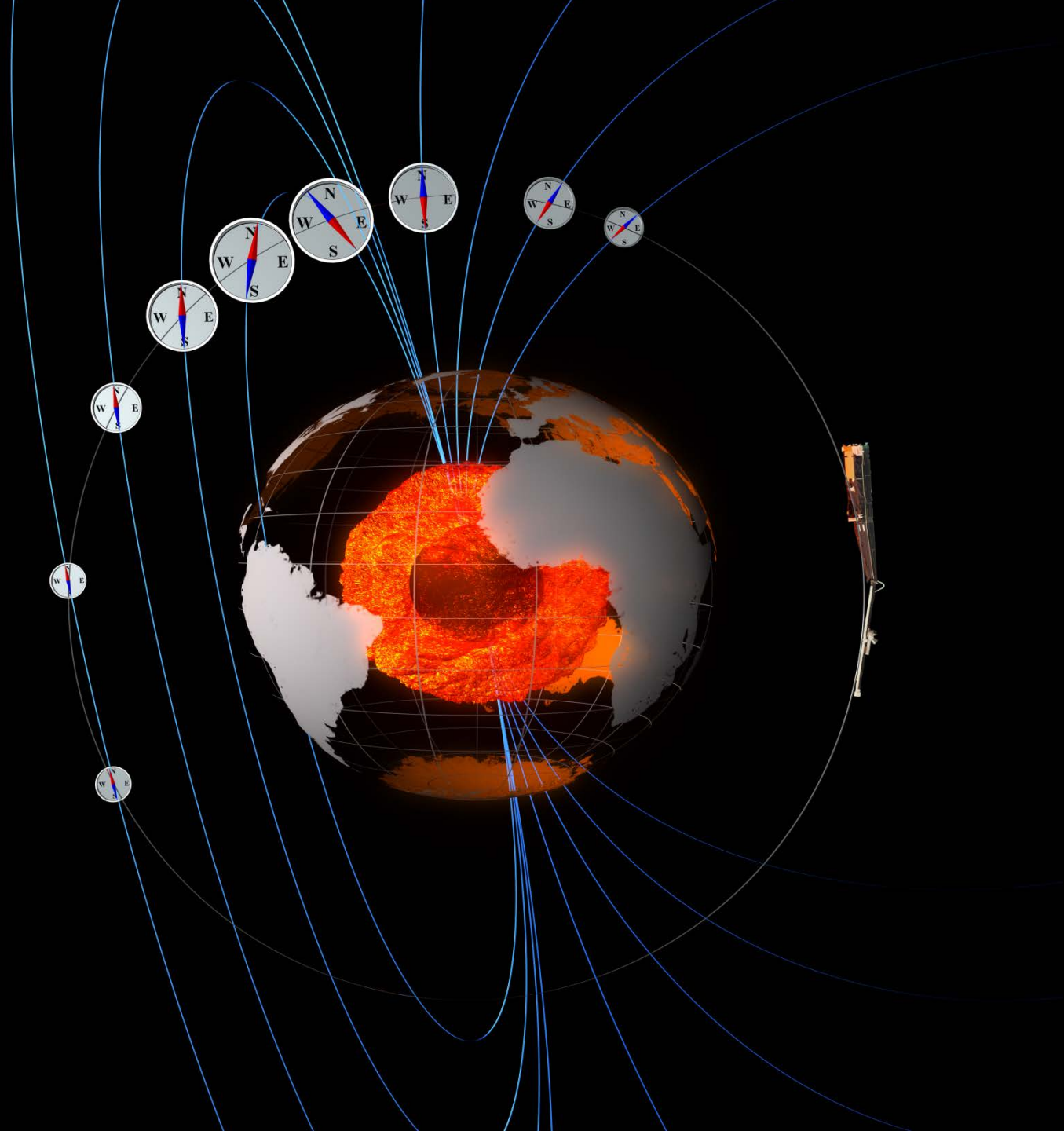


- Compute Inclination, Magnetic Azimuth, Tool Face
- True Azimuth = Magnetic Azimuth + Declination

Magnetic Elements Given by Model



Main Field Originating in the Earth's Core

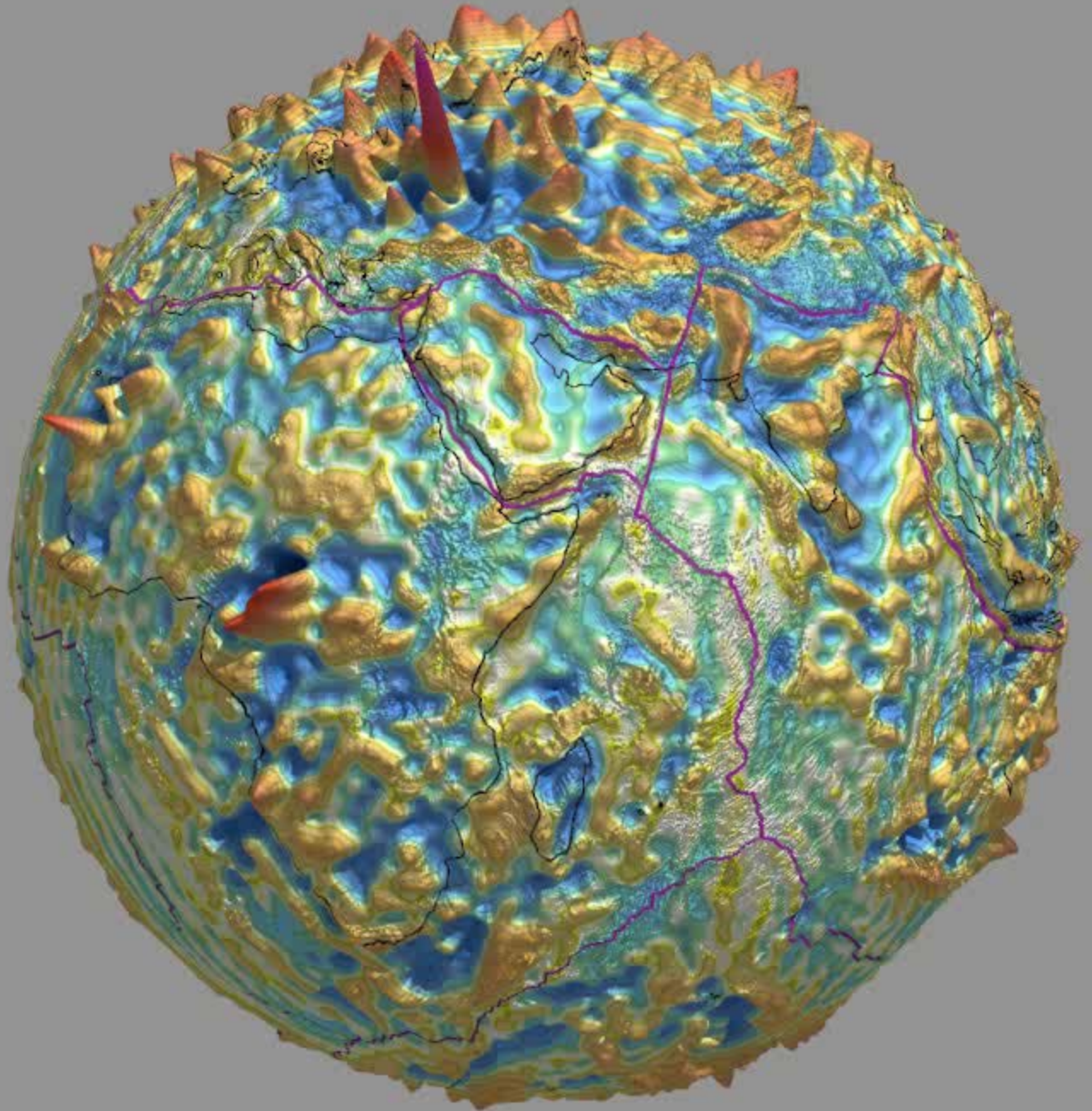


European
Space Agency,
Swarm project

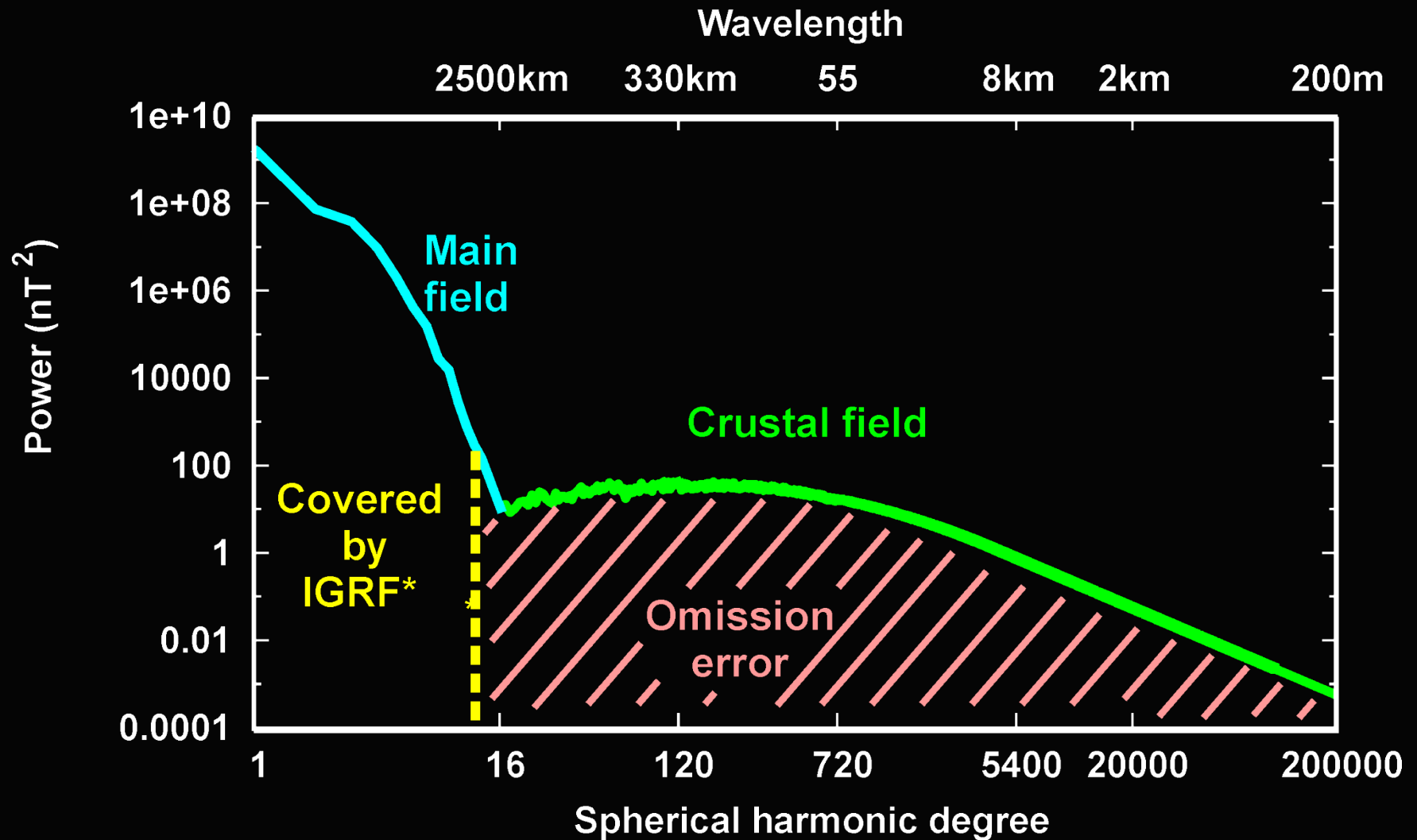
Crustal magnetic field as seen by CHAMP satellite

*Vertical
component of
the magnetic
field*

MF7 model
Animation by
Rother and Maus

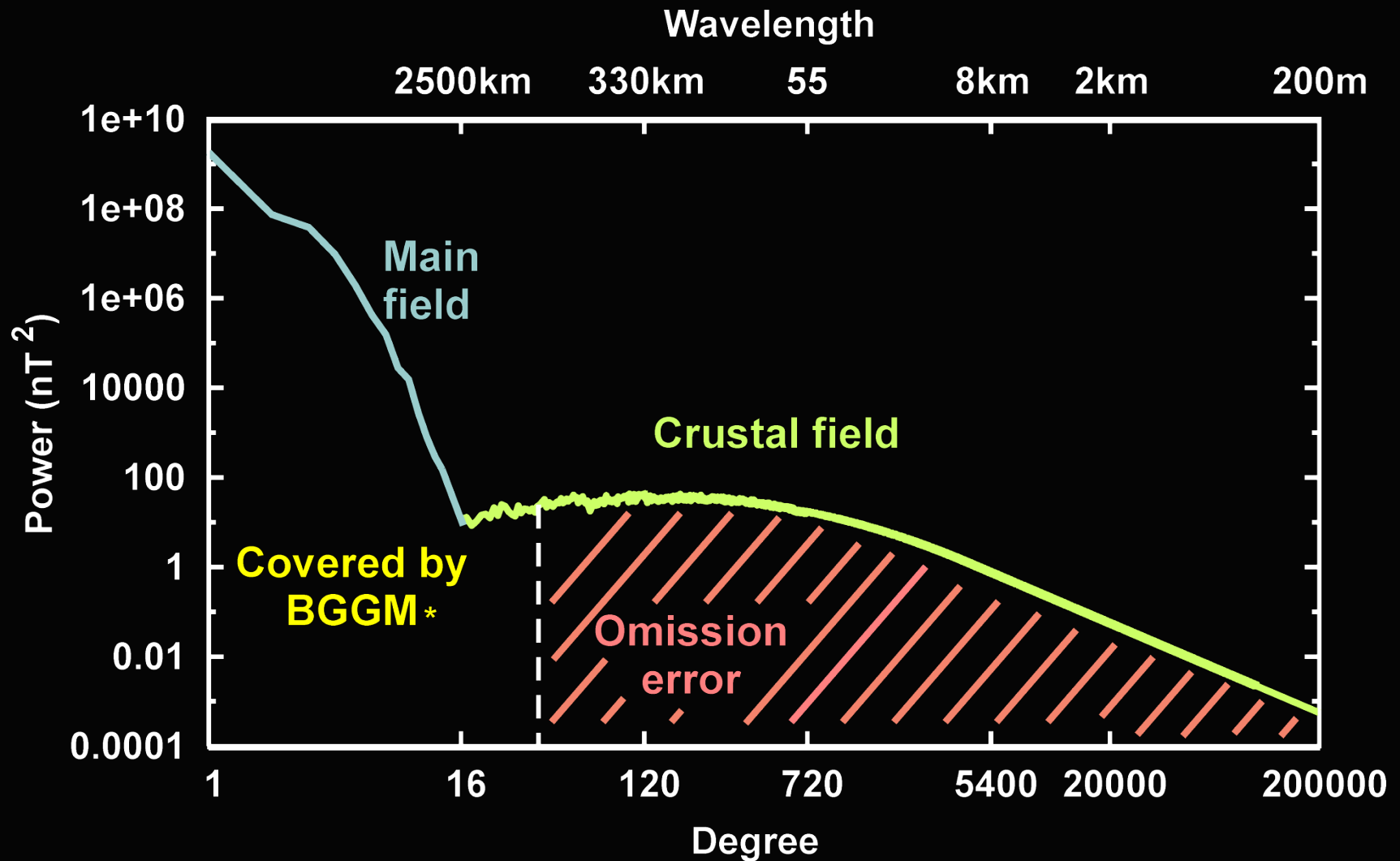


Omission Error: IGRF



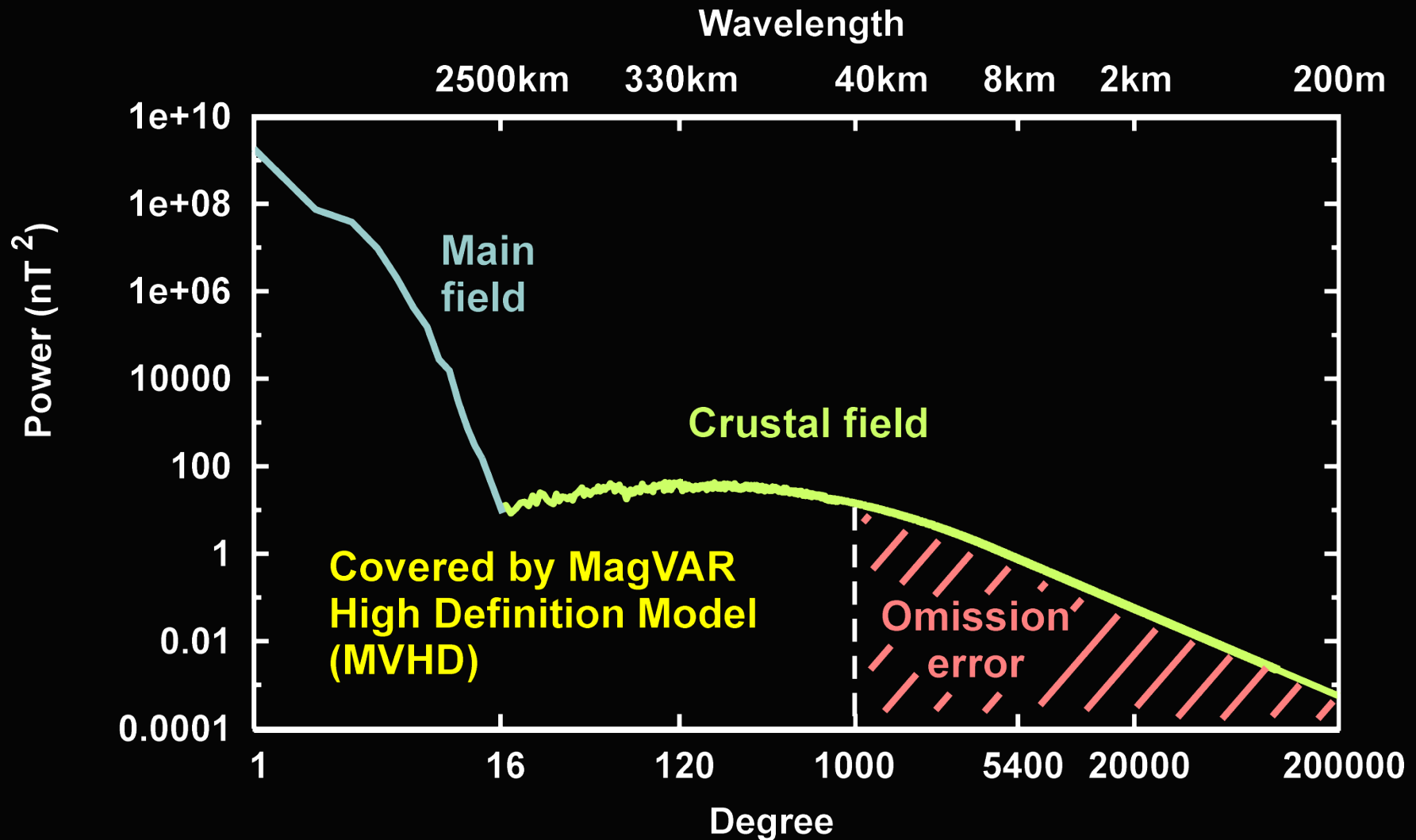
*IGRF = International Geomagnetic Reference Field

Omission Error: BGGM



*BGGM = BGS Global Geomagnetic Model

Latest High Definition Model (MVHD)

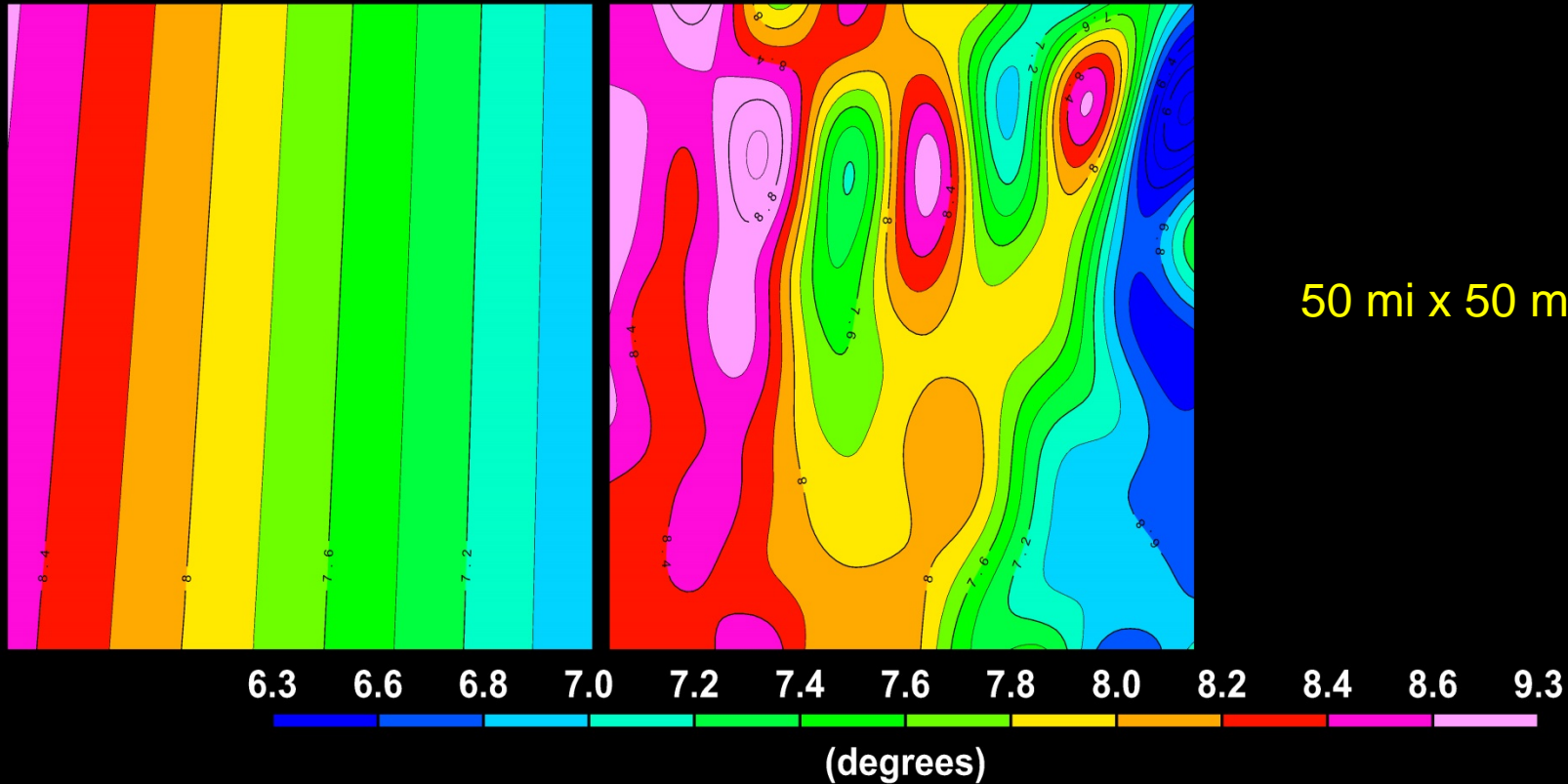


For questions about the MagVAR High Definition Model (MVHD) contact maginfo@magvar.com

Declination Comparison

Main Field

MVHD



Global Model Calculator

Slide 13 of 35

MagVAR Calculator-MVGM 2.2.0 bu-4

File Data Tools Window About Help

Search Source: 32039 NAD27 / Texas Central Info

Vertical Reference Point: 2500 Units: Meter Grid Convergence: -0.79

True Vertical Depth: 9000 Date: 04-Feb-2015 Scale Factor: 0.99995

X: 1522000.0 foot_survey_us EAST

Y: 630000.0 foot_survey_us NORTH

Target: 4326 WGS 84

Lat: 31.39001° NORTH

31° 23' 24.02"

Long: -101.86552° EAST

-101° 51' 55.86" Transform

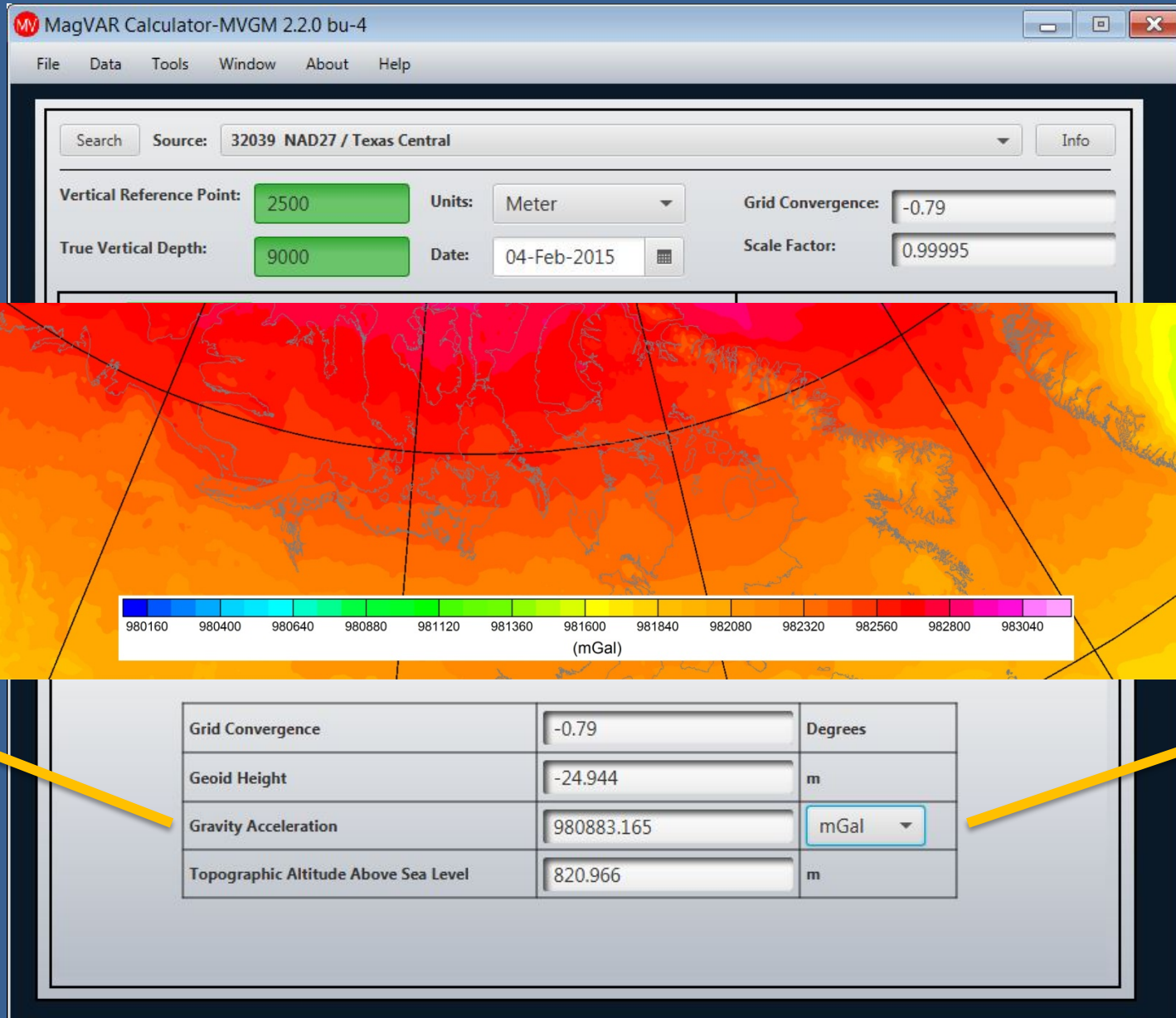
Global Geomagnetic Models Calculate Report Locate

Summary WMM IGRF EMM MVHD MVSD Misc Residual

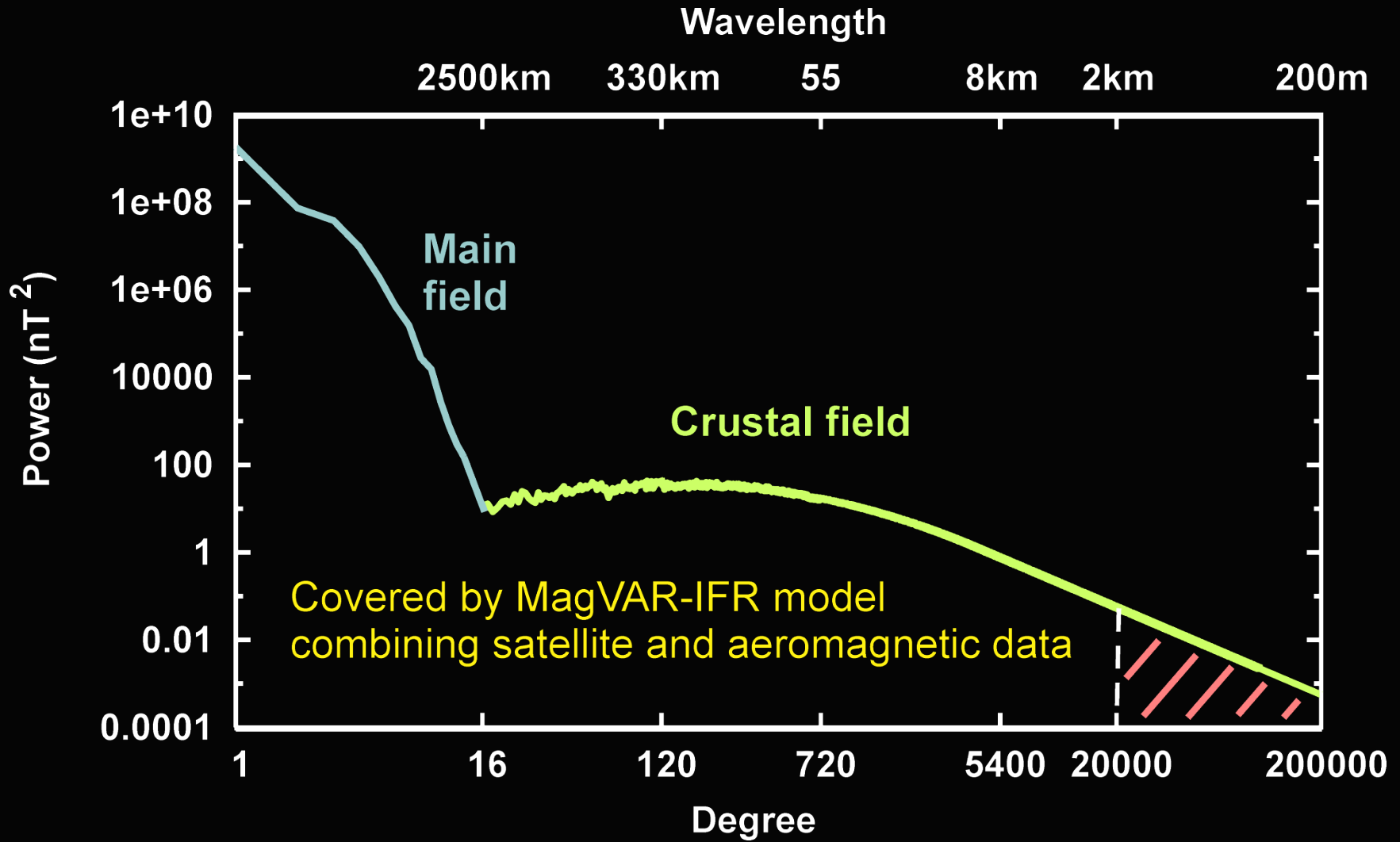
	Declination	Error	Dip	Error	Total Field	Error
WMM:	6.32	+/- 0.50	59.59	+/- 0.24	48094.5	+/- 157.00
IGRF:	6.28	+/- 0.50	59.59	+/- 0.24	48100.8	+/- 157.00
● EMM:	6.76	+/- 0.45	59.89	+/- 0.21	48134.4	+/- 139.00
MVSD:	6.40	+/- 0.41	59.58	+/- 0.20	48064.5	+/- 130.00
● MVHD:	6.85	+/- 0.34	59.94	+/- 0.16	48041.0	+/- 107.00
MagVAR-IFR:	Not Available	+/- 0.09	Not Available	+/- 0.06	Not Available	+/- 60.15

Global Model Calculator

Slide 14 of 35



Omission error: MagVAR-IFR



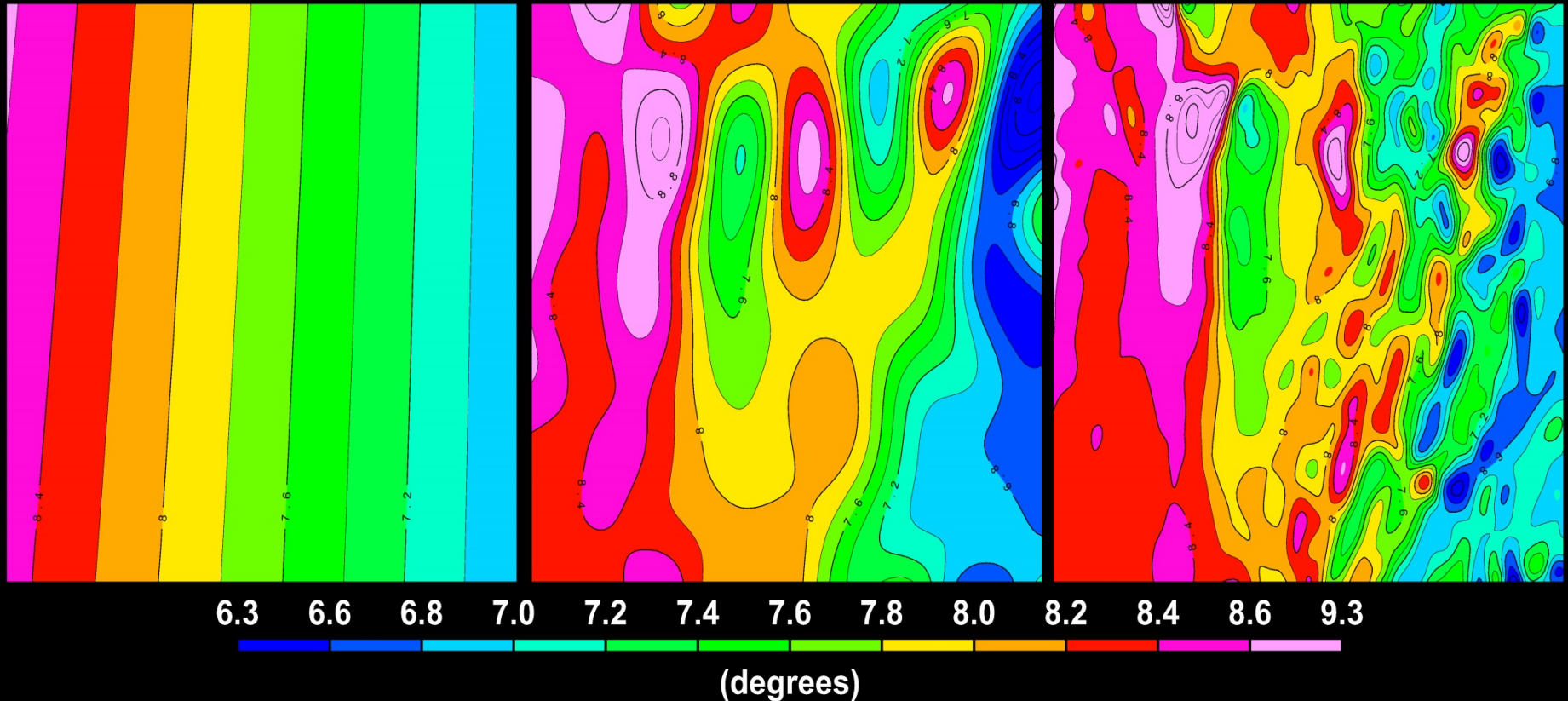
For questions about MagVAR In-field Referencing (IFR) contact maginfo@magvar.com

Model Comparison

Main Field

MVHD

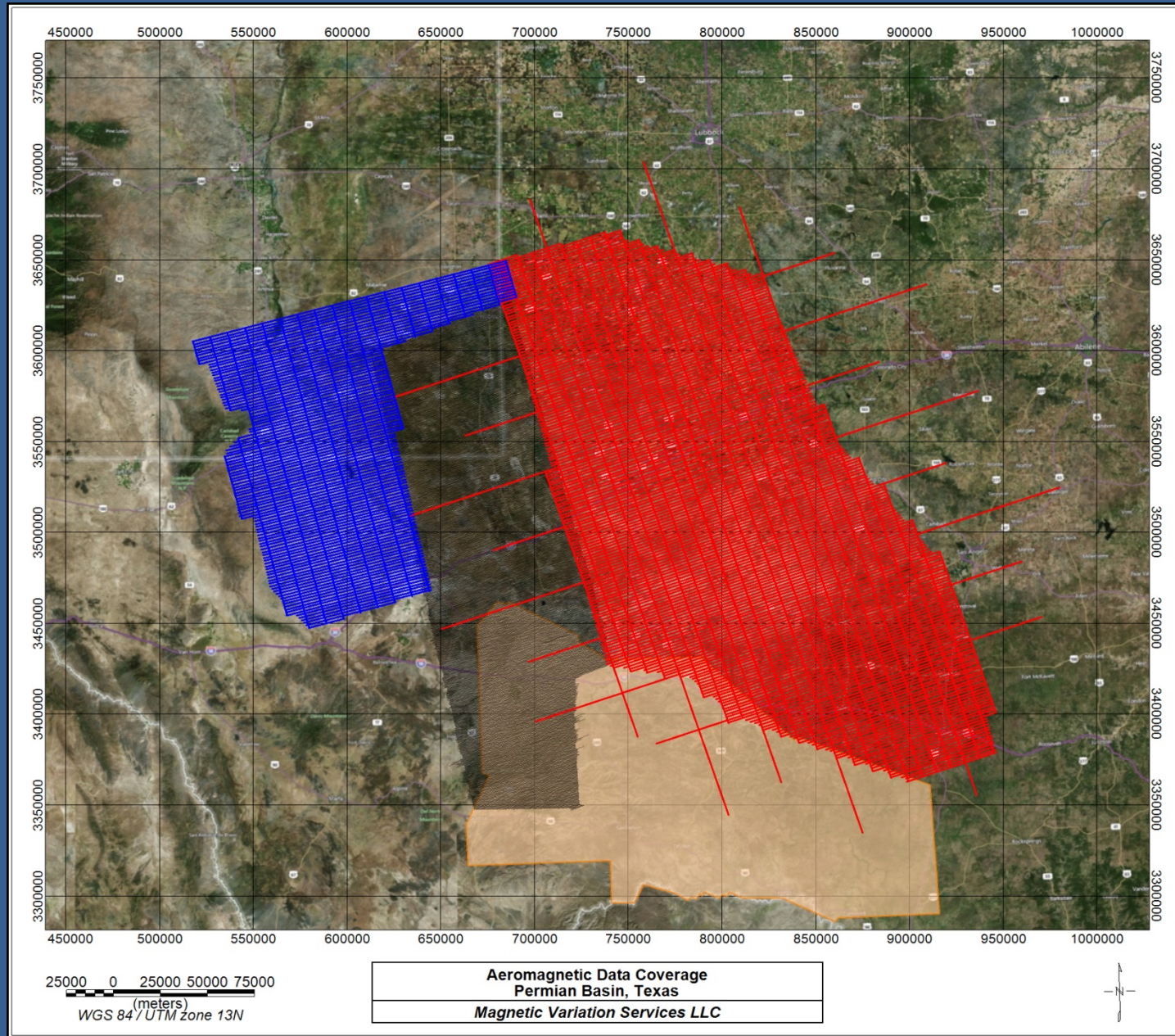
MagVAR IFR



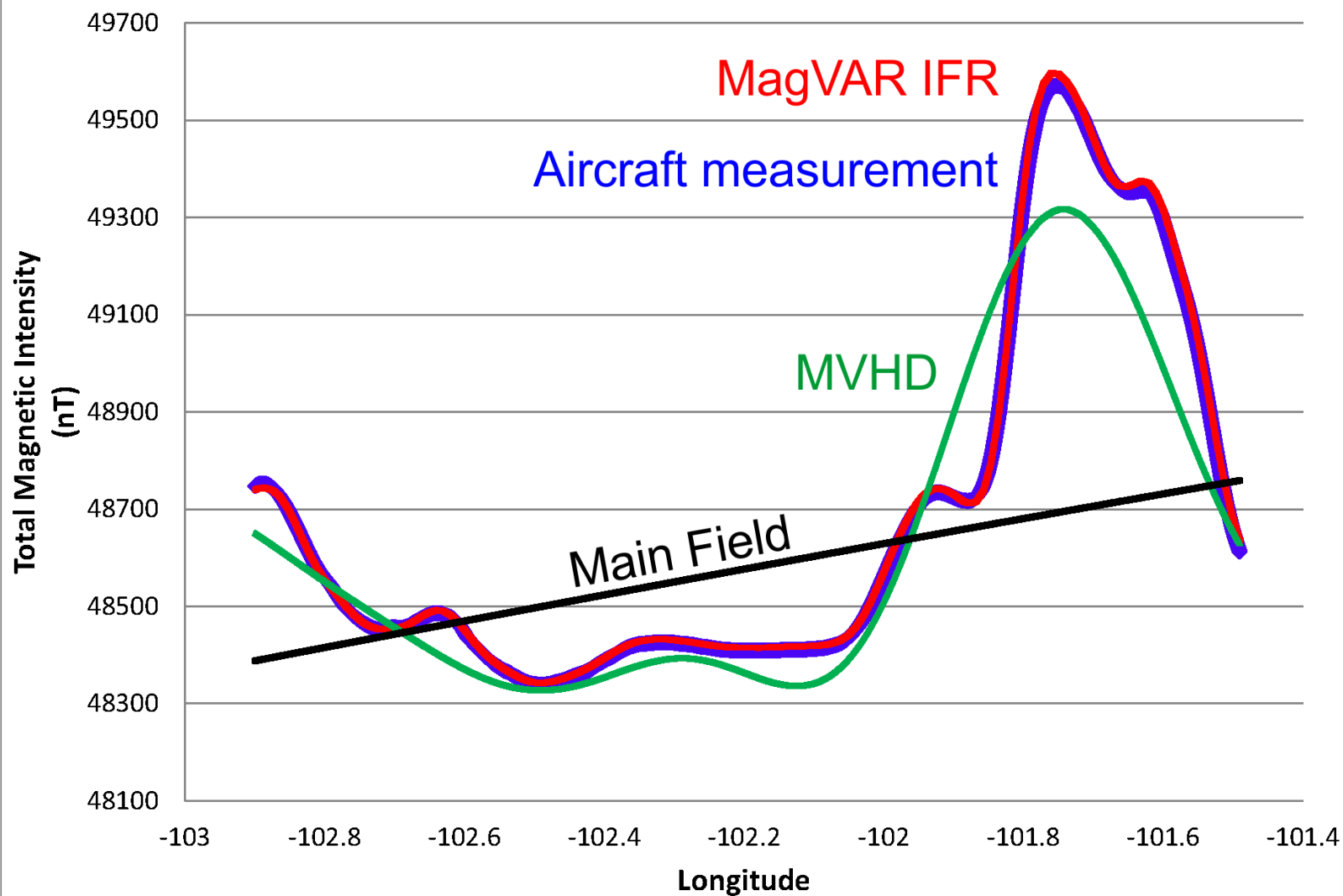
The most detailed magnetic reference is given by In-Field Referencing (IFR)

Permian Basin Aeromagnetic Surveys

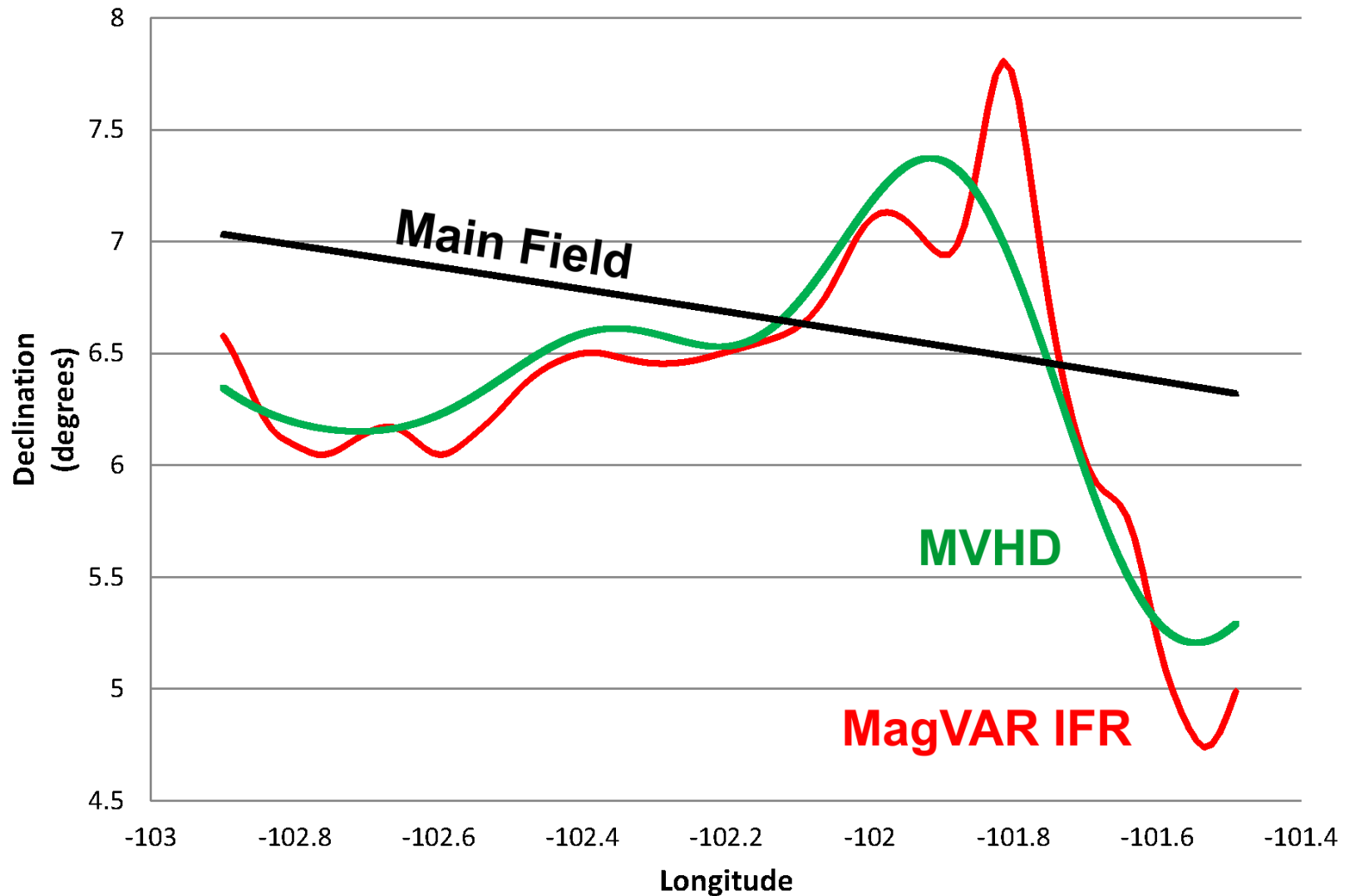
Slide 17 of 35



Total Field Comparison



Declination Comparison

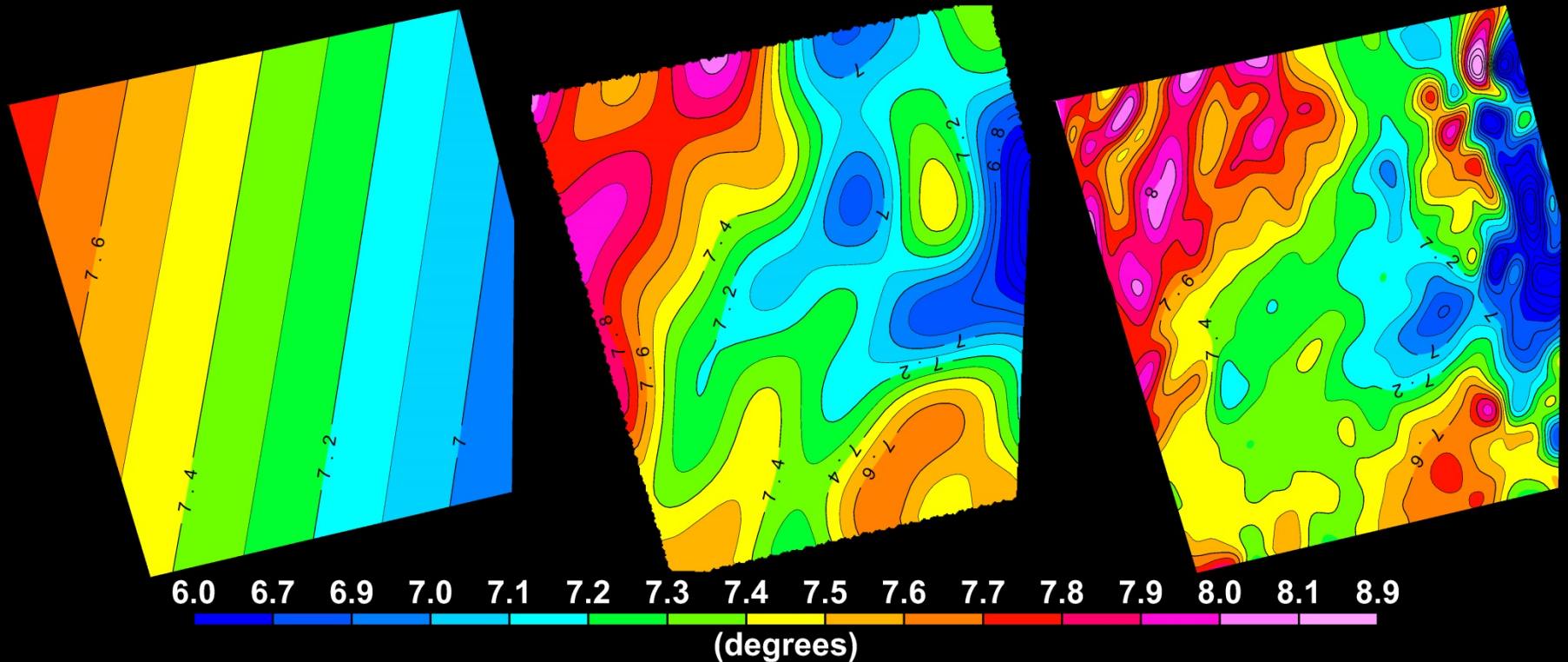


Declination at 10,000 ft TVD

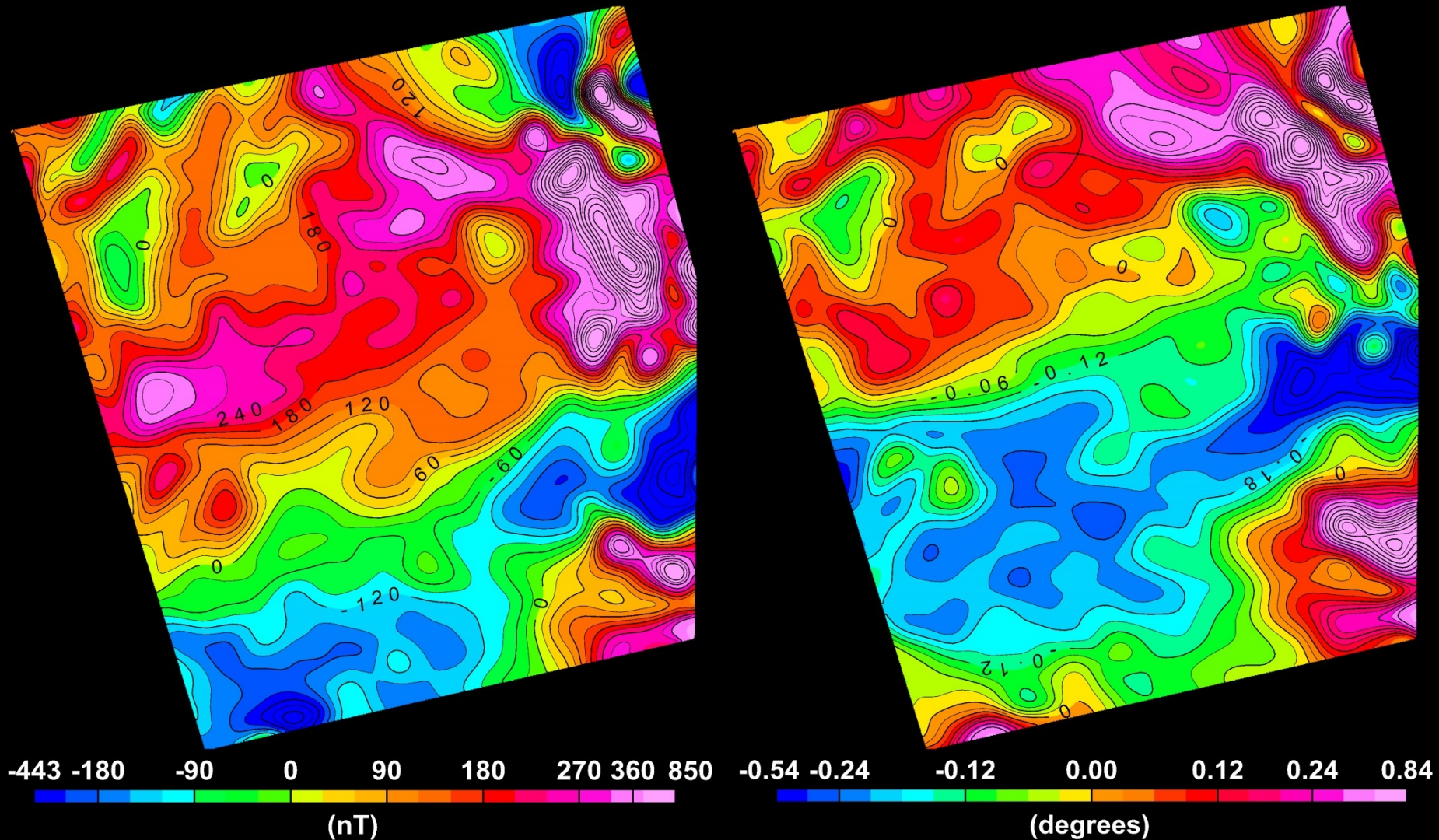
Main Field

MVHD

IFR



Total Field and Dip anomalies (IFR)



MagVAR IFR Calculator

Graphical User Interface provides magnetic reference values and gradients

MagVAR IFR Calculator-MVLM 4.0.2


File Windows Data Tools About Help

Complete Field
Coordinate System : NAD27 / Texas SP Central Zone (4203) US feet

Eastings <USft>
Northings <USft>
True Vertical Depth <USft> - **Vertical Reference Pt** <USft>
Depth below MSL =
Date <dd-mmm-yyyy>

Declination: degrees **Dip:** degrees **Btotal:** nT

	Declination		Dip		Btotal	
Eastward	<input type="text" value="0.043"/>	deg/1000ft	<input type="text" value="0.013"/>	deg/1000ft	<input type="text" value="18.6"/>	nT/1000ft
Northward	<input type="text" value="-0.011"/>	deg/1000ft	<input type="text" value="-0.028"/>	deg/1000ft	<input type="text" value="-10.1"/>	nT/1000ft
Downward	<input type="text" value="0.056"/>	deg/1000ft	<input type="text" value="0.001"/>	deg/1000ft	<input type="text" value="-12.9"/>	nT/1000ft
Over Time	<input type="text" value="-0.107"/>	deg/year	<input type="text" value="-0.006"/>	deg/year	<input type="text" value="-115.8"/>	nT/year

 Magnetic Variation Services LLC, Copyright (C) 2012

Export well plan from data base

COMPASS - edmp

File Edit View Analysis Plot Report Tools Window Help

Units: API - US Survey Feet Datum: Maund_23_1 Default @ 747.1usft TVDs to System Local: Slot North: True

Status

Recent: Maund_23_1 (US SOUTHERN REGION PLANNING, MAUND DPA, Maund_23_1-6, Maund_23_1, Maund_23_1)

Filter: <none>

Current Selection & Status

- US SOUTHERN REGION
- MAUND DPA
- Maund_23_1-6
- Maund_23_1

Datum Information

Datum: Maund_23_1 Default
Datum Elevation: 747.1usft
Air Gap (Ground): 0.0usft
Ground Elevation: 747.1usft
Mean Sea Level

Local Origin

0.0usft
0.0usft
(Slot 0,0)

North Ref

Magnetic: 5.49°

CHUPADERA DPA
COCHINA EAST DPA
COCHINA WEST DPA
DENTONIO DPA
DIAMOND DPA
FOGMT DPA
FRIDAY DPA
LA BANDERA DPA
MAUND DPA
Maund_23_1-6
Maund_23_1
Maund_23_1
Maund_23_2
Maund_23_3
Maund_23_4
Maund_23_5
Maund_23_6
Maund_23_7-12
Maund_TEST_Pad
Maund_TEST_Pad
Maund_TEST_Surf
RANCHO DPA
SOUTH SPUR DPA
STANLEY DPA
STANLEY DPA

Export

Transfer File...
Survey Data
DEX

Casings...
Formations...
Reports...
PropertiesAlt+Enter

Depths relative to:

Casings
Formations
Planned Wellpath
Survey/Plan Program
Maund_23_1 (Maund_23_1)

151 stations to 12663.4usft

Tool
MWD+IFR

Auto-generated IFR Values for Sections

MagVAR Calculator

File Windows Data Tools About Help

Complete Field

Coordin

Select File

Select input file format

File Format: Compass

Originator: MagVAR

Location: Bakken

Notes:

Vertical Reference Point: 2200

Select Input File:

Select Output File:

QC Thresholds:

Azimuth: ☐ Grid ☐ True

Tool Code: Please Select Tool Code

Sigma Multplier:

Partitions: ☐ User defined ☐ Center of lateral ☒ Auto generated

Range Thresholds:

Label	Dec	Dip	BTotol	MD Range	Date	
16"	0.2	0.2	100	0 - 9000	08-Jul-2014	✗
12"	0.1	0.1	50	9000.1 - 11000	15-Jul-2014	✗
8.5"	0.1	0.1	50	11000.1 - MAX_RANGE	22-Jul-2014	✗

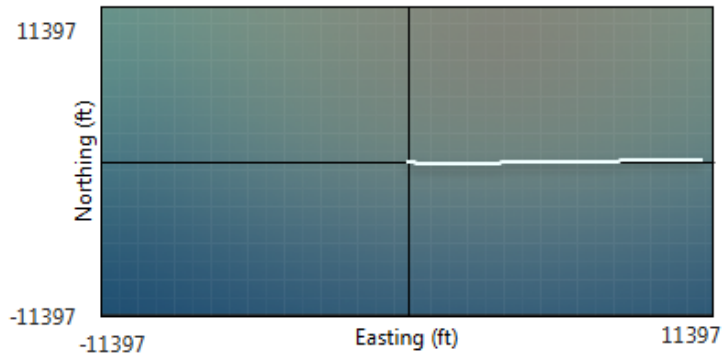
Add New Section

Northward 0.003 deg/1000ft 0.019

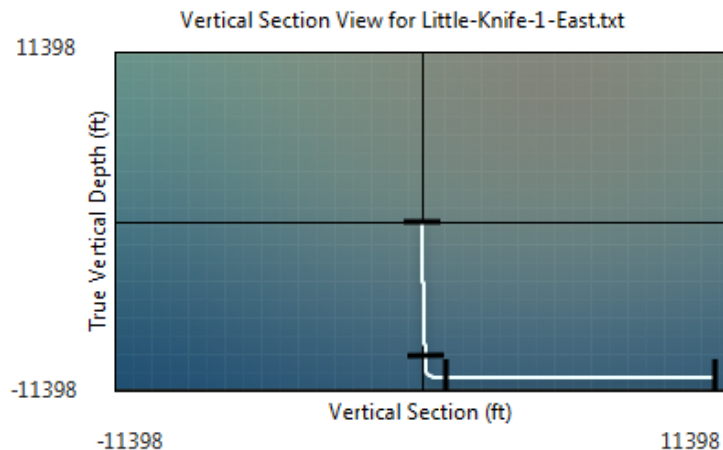
Downward -0.003 deg/1000ft 0.008 deg/1000ft 26.8 nT/1000ft

Auto-generated IFR Well Segments

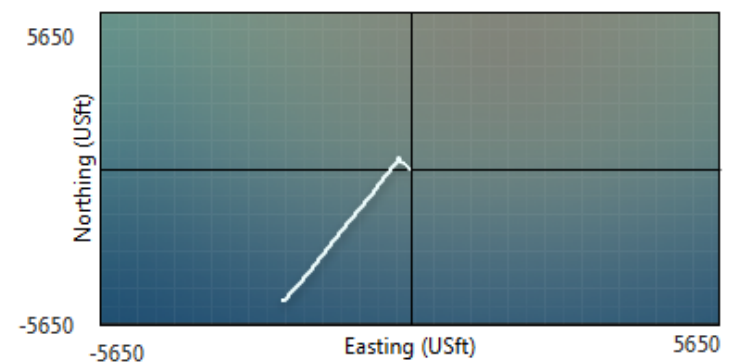
Small magnetic gradients



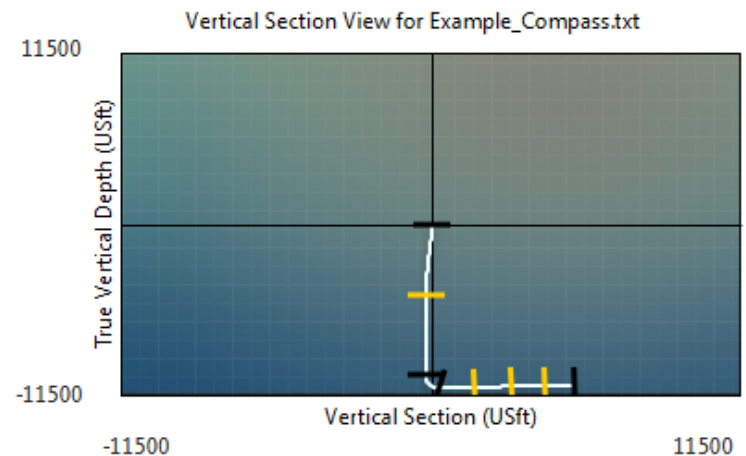
Easting Offset: 1337375.32
Northing Offset: 146450.65



Large magnetic gradients



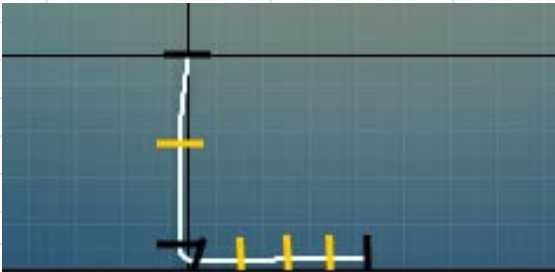
Easting Offset: 1527859.0
Northing Offset: 747045.0



Output File for “auto-generated”

Example_Compass#_2014-08-15.xls [Compatibility Mode]

	A	B	C	D	E	F	G	H	I
1	MagVAR-IFR Calculator Report				MagVAR				
2	Version:	4.0.2							
3									
4	Lease Block: Permian Basin								
5	Input Data: Aeromagnetic surveys MV-A1, NURE, and CHAMP satellite data								
6	Conditions Of Use: Exclusive license by Pioneer Natural Resources								
7	Coordinate System: NAD27 / Texas SP Central Zone (4203) US feet								
8	Location:								
9	Vertical Reference Point:	0 USft							
10	Report Date:	15-Aug-2014							
11	Location on map								
12	This is the:	Summary							
13	Originator:	MagVAR							
14	Notes:								
15	Summary statistics for the entire well path:								
16			Btotal	Dip	Dec	Grid Convergence	Total Correction	Start MD	End MD
17			nT	degrees	degrees	degrees	degrees	USft	USft
18	Mean:		47949.1	59.86	6.35	-0.78	7.13	0.0	15000.0
19	Range:		51.0	0.06	0.03	0.01	0.02	0.0	15000.0
20									
21	Recommended Segments:								
22	Sec_1_20" Seg_1:		47930.4	59.88	6.35	-0.78	7.13	0.0	4141.0
23	Sec_1_20" Seg_2:		47947.6	59.86	6.35	-0.78	7.13	4141.0	8935.0
24	Sec_2_12.5" Seg_1:		47957.9	59.86	6.36	-0.78	7.14	8935.0	9953.0
25	Sec_3_8" Seg_1:		47958.3	59.85	6.35	-0.78	7.13	9953.0	11260.0
26	Sec_3_8" Seg_2:		47962.3	59.85	6.35	-0.78	7.13	11260.0	12640.0
27	Sec_3_8" Seg_3:		47966.6	59.84	6.34	-0.79	7.13	12640.0	13875.0
28	Sec_3_8" Seg_4:		47970.8	59.83	6.34	-0.79	7.13	13875.0	15000.0
29									
30									



Vertical Section (USft)

Summary | Sec_1_20" Seg_1 | Sec_1_20" Seg_2 | Sec_2_12.5" Seg_1 | Sec_3_8" |

Uncertainties in West TX

Lateral Uncertainty at TD

Well Azim.	Lateral Length	MWD	MWD +IFR1	MWD +IFR1+MS
	(ft)	(ft)	(ft)	(ft)
E	11000	439	390 (-11%)	173 (-61%)
SE	11000	387	329 (-15%)	160 (-59%)
S	11000	259	161 (-38%)	129 (-50%)

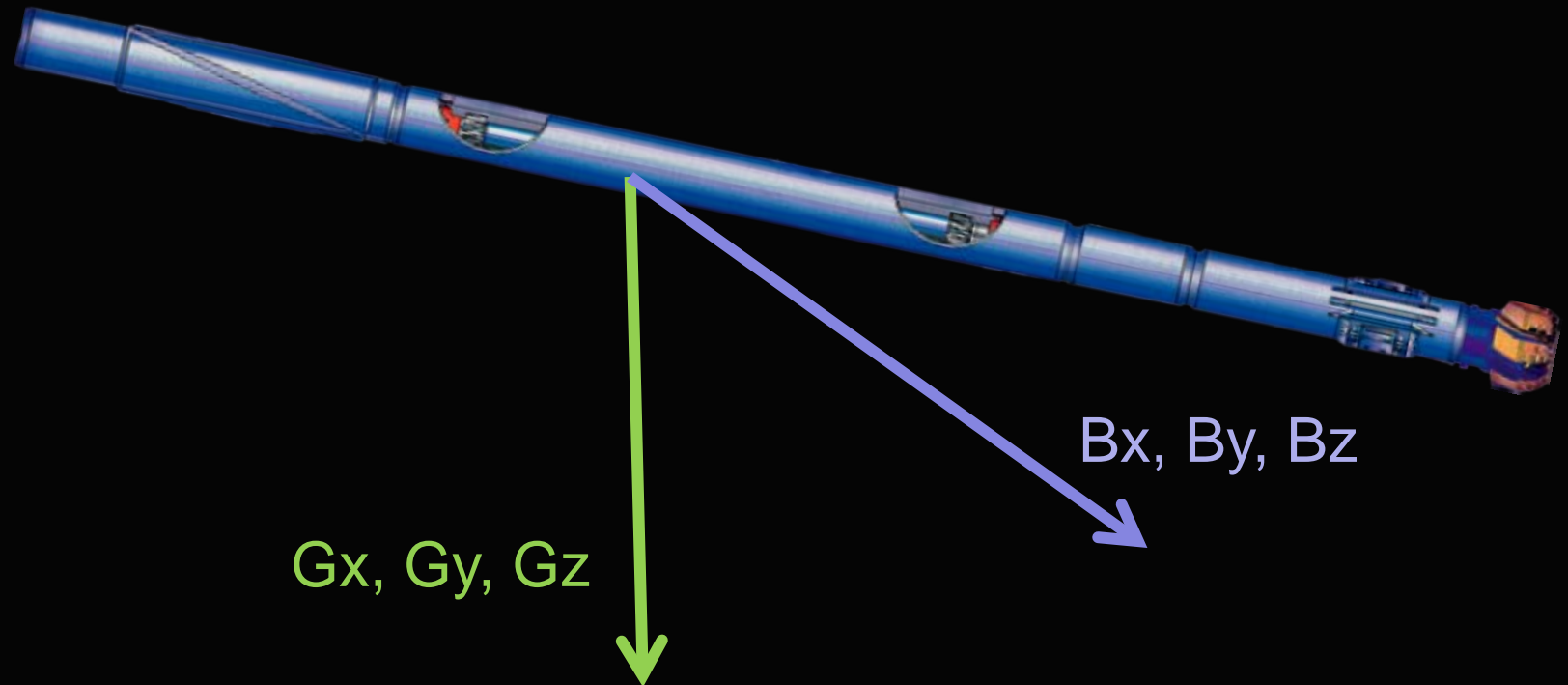
Vertical Uncertainty at TD

TVD	MWD	MWD+IFR1+SAG+MS
10600 ft	119 ft	71 ft (-40%)

3D Ellipsoids given
for 95% confidence
interval = 2.79 sigma

Error model:
ISCWSA OWSG

QC and Correction of Raw MWD Data

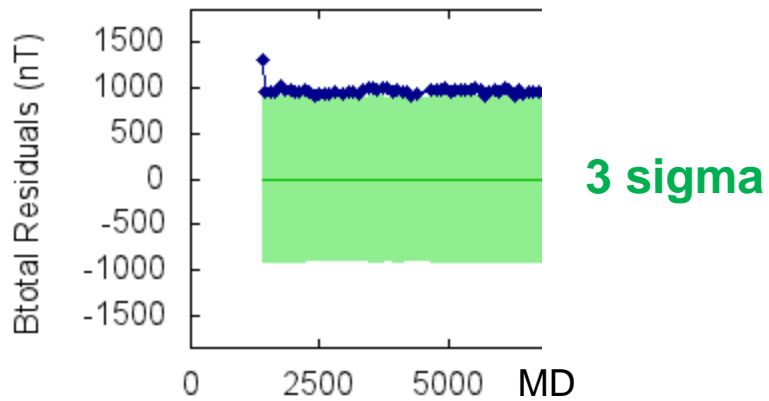


Measure 6 quantities → get 6 parameters:

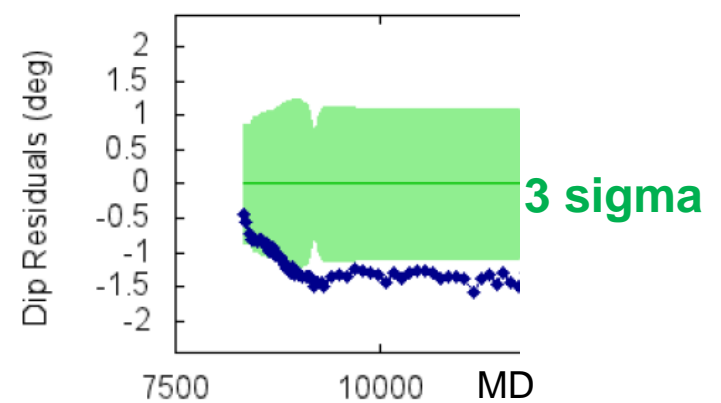
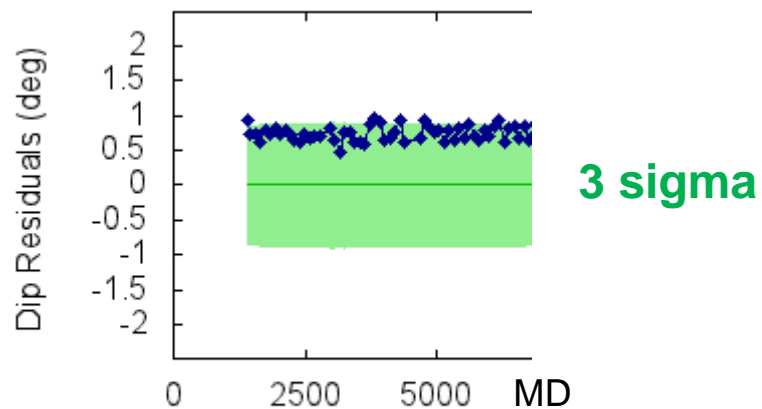
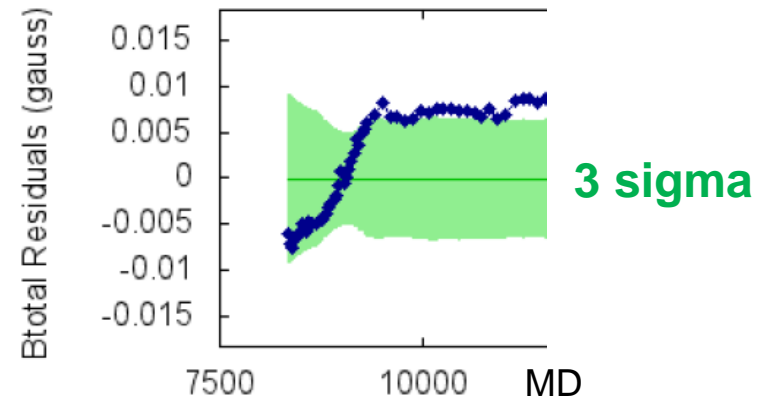
- Inclination, Magnetic Azimuth, Tool Face (use for steering!)
- Gtotal, Btotal, Dip (use for QC and Corrections!)

Examples of Raw Data QC

Raw data (MWD tool code)



Raw data (MWD tool code)

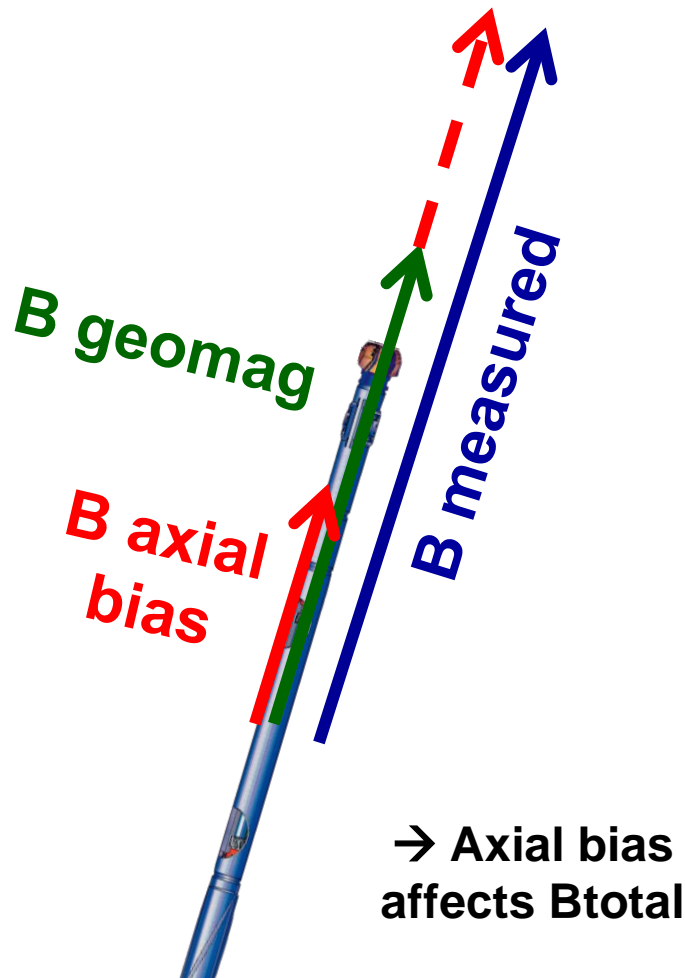


QC Parameter Errors Depend on Wellbore Orientation

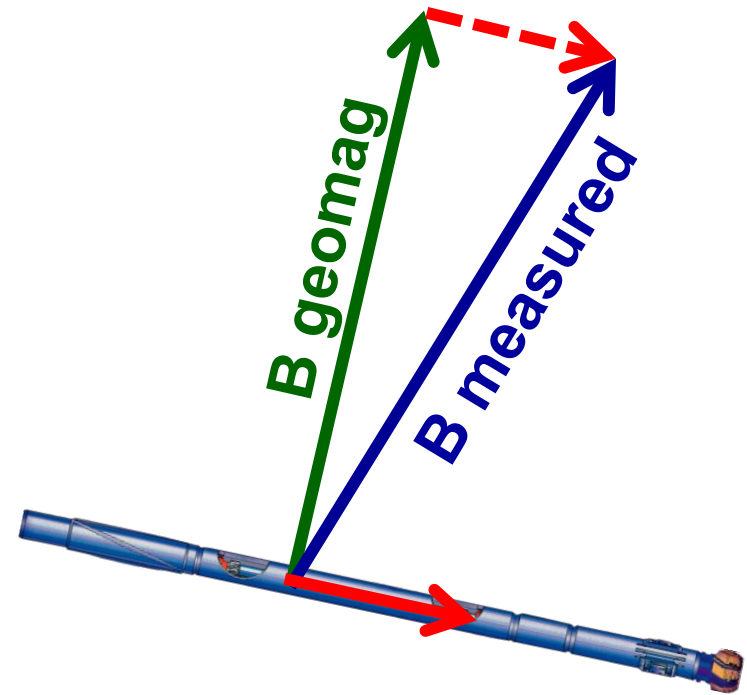
Slide 30 of 35

Example: Contribution of axial bias to error in B_{total}

Wellbore parallel to magnetic field
(plan view)



Wellbore oriented magnetic east
(plan view)



Computing QC Thresholds for Tool Codes

Select File

Select input file format

File Format:

Compass

QC Thresholds:

☒

Or

Range Thresholds:

Label	Dec	Dip	BTotal	MD Range		Date	
20"	0.1	0.1	50	0	- 7000	19-Jul-2014	✗
12.5"	0.1	0.1	50	7000.1	- 8000	24-Jul-2014	✗
8"	0.1	0.1	50	8000.1	- MAX_RANGE	30-Jul-2014	✗

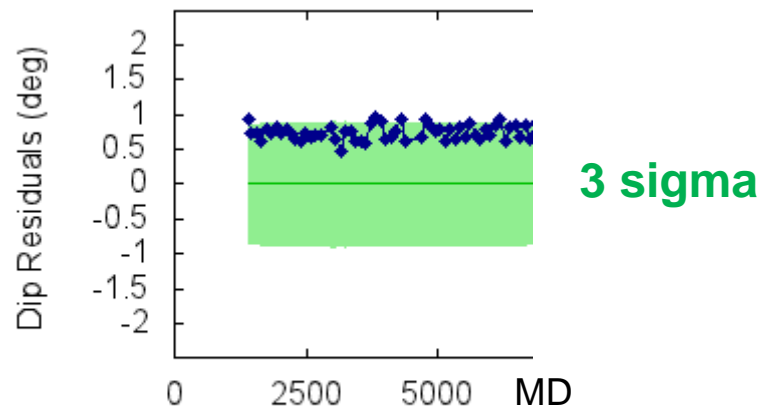
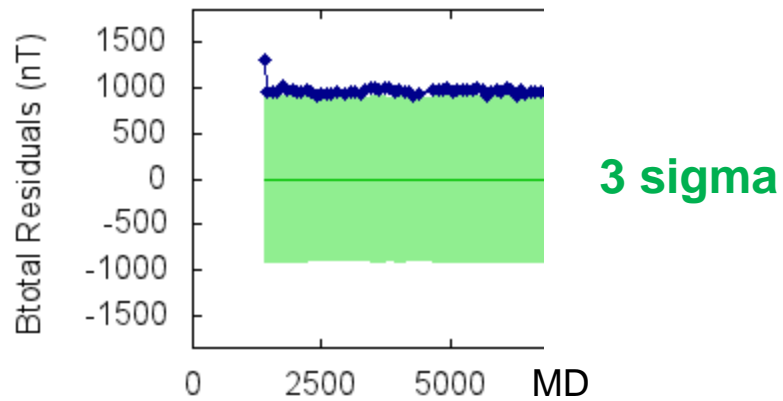
Add New Section

QC Criteria:

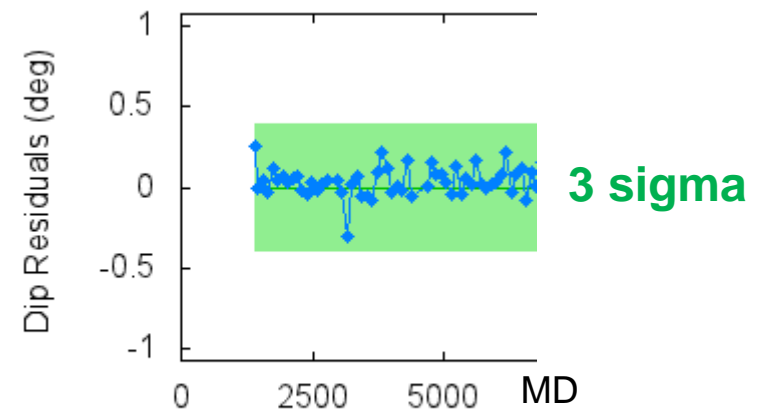
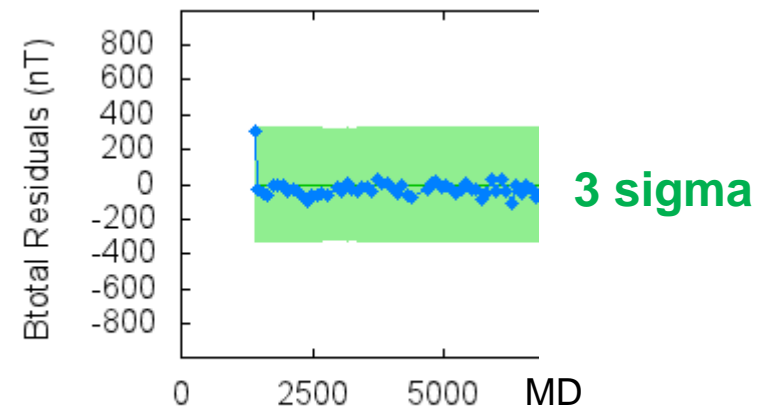
Label	Tool Selection	Sigma Multiplier
Section : 20"	A.01. MWD	3
Section : 12.5"	A.09. MWD+IFR1	3
Section : 8"	A.15. MWD+IFR1+MS	3

Multi-Station Analysis Correction

Raw data (MWD tool code)



IFR and MSA corrected data (MWD+IFR1+MS tool code)



Note the tighter QC thresholds!

Relevant Tool Codes for Well Planning and Anti-collision Scans

Tool Code	Magnetic reference model	Survey corrections	EOU*
MWD+IGRF	Global IGRF or WMM	-	+10%
MWD	Global BGGM or MagVAR MVSD	-	Standard
MWD+HDGM	Global HDGM or MagVAR MVHD	-	-10%
MWD+IFR1	Local In-Field Referencing (IFR1)	-	-30%
MWD+IFR1+MS	Local In-Field Referencing (IFR1)	Multi-Station	-50%



More Accurate

*Approximate values, actual EOU sizes depend on location and orientation of wellbore

New set of consolidated error models from the Operator Wellbore Survey Group
These are available from Landmark as IPMs for Compass.

Importance of Raw Sensor Data

Record and archive the raw 6-axis sensor data

- With MD, date, time and tool run for each survey
- Sufficient precision (at least 4 significant digits)

The raw data can be read from tool memory

- Needs synchronization with MD

Conclusions

- Wellbore positions have significant uncertainties
- Uncertainties can be reduced by 50%
 - *First step: Produce a local IFR magnetic model*
 - *Second step: Apply Quality Control and use multi-station analysis methods to correct the raw MWD sensor data*
- IFR and survey quality management significantly improve well placement accuracy

For questions about the MagVAR High Definition Model (MVHD), MagVAR IFR and the software shown in this presentation please contact maginfo@magvar.com