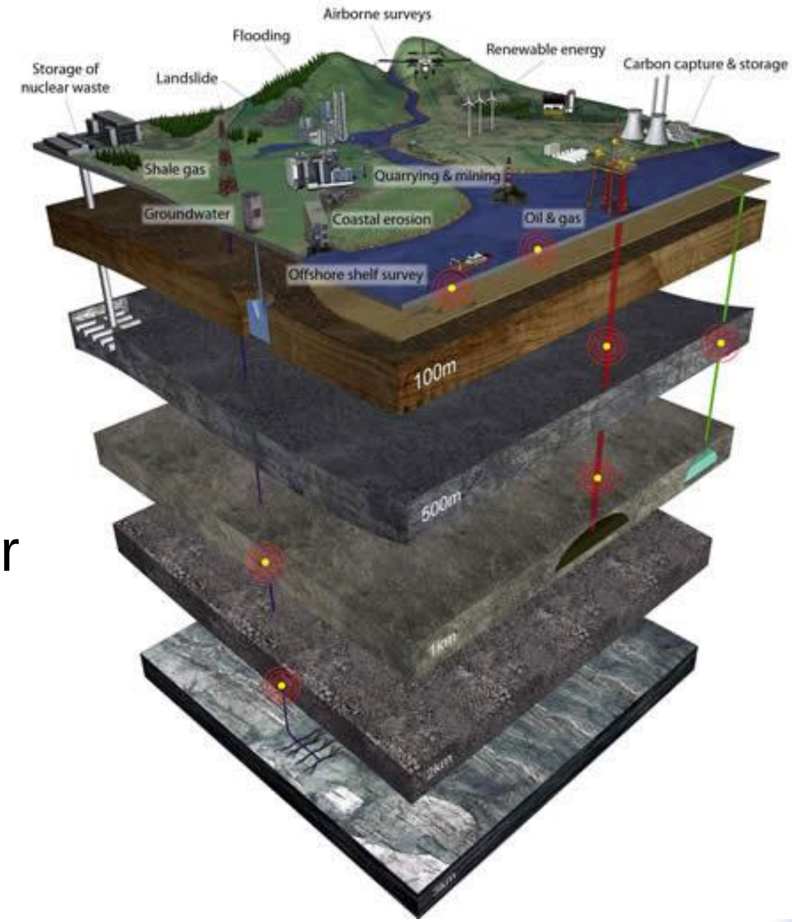
ESIOS Energy Security & Innovation Observing System for the Subsurface

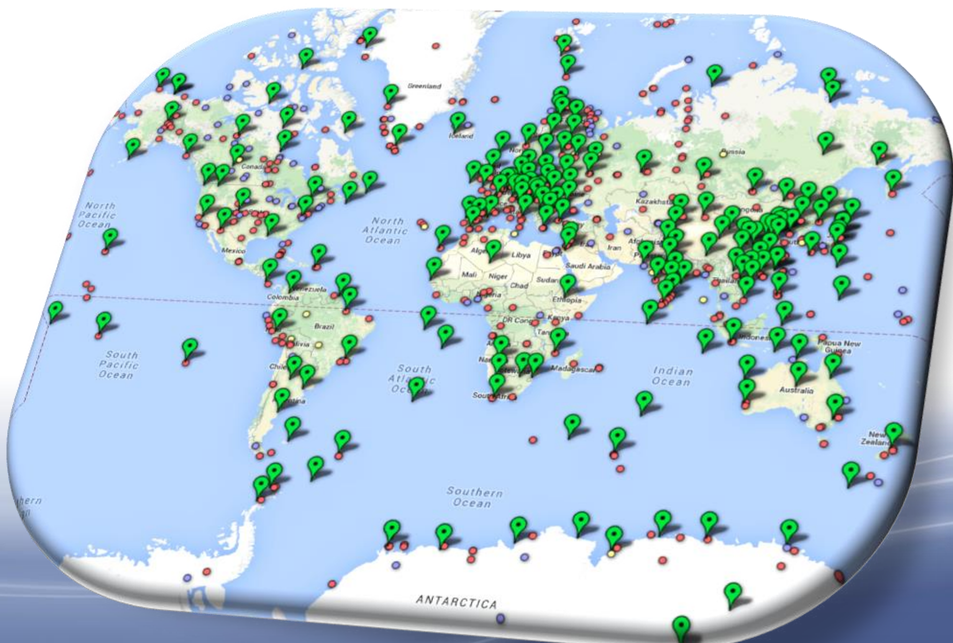
- £31M UK Government funded science research project
  - Monitoring and observing the subsurface
  - Independent scientific evidence for boosting drilling efficiency etc.
  - e.g. CCS, shale gas, gas storage
- Two deep boreholes (>3km TVD) planned in Cheshire, UK
- Opportunity to suggest experiments or useful ideas now (30 Oct 2015)
- Happy to help coordinate or answer further questions:
  Ciarán Beggan [ciar@bgs.ac.uk]



More detail: http://www.nerc.ac.uk/funding/available/capital/esios/

External Field Variations and Critical Observatory Distance (COD)

Ellen Clarke, Laurence Billingham
and Ciarán Beggan



Overview

- Motivation

  IFR2 uncertainties – how far is the “cut-off” distance from observatory to drill site?

- Geomagnetic reference

- Data - selection and processing
  - magnetic observatories/permanent variometers
  - focus (initially) on higher geomagnetic latitudes
  - we want robust statistics – so need a lot of data

- Results - including seasonal and solar cycle variations

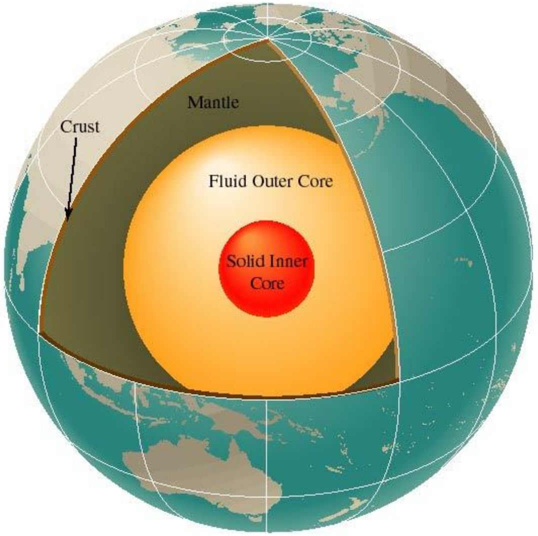
Motivation

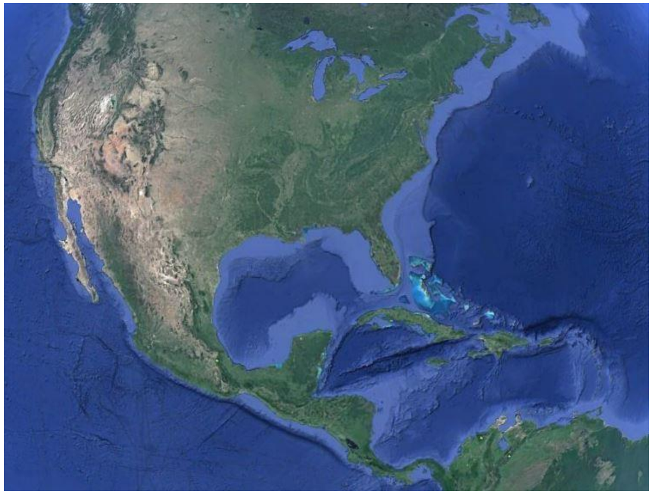
- To improve geomagnetic referencing for MWD (IFR2)
- Provide a more robust answer to the questions:

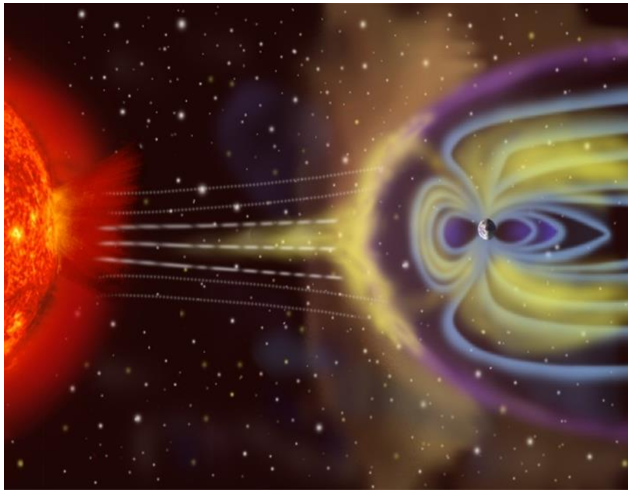
  How far away can an observatory be from the drill site and still be useful for IFR2?

  What is the uncertainty in the estimates of the external field (IFR2)?
- Provide information to industry on the effectiveness and convenience of making use of existing long-running magnetic observatories
- Provide information to observatory operators worldwide on the worth (and potential source of funding) of their data

Geomagnetic Reference for MWD







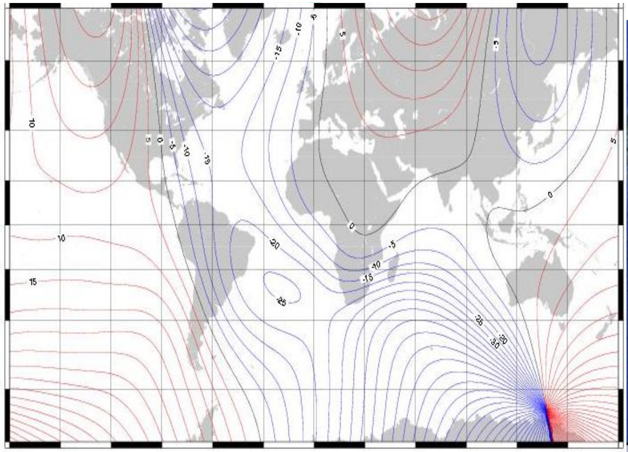
Core (or main) field | + Local crustal field | External field

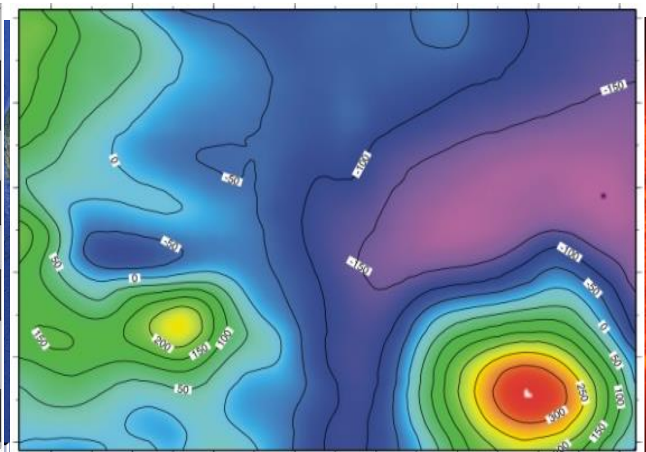
Standard MWD | MWD+IFR1 | MWD+IFR2

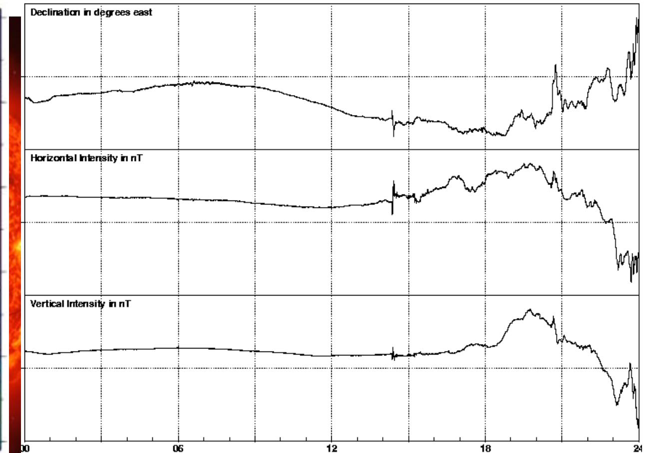
Including more sources of the Earth's magnetic field

- Reduction in uncertainty

Geomagnetic Reference for MWD





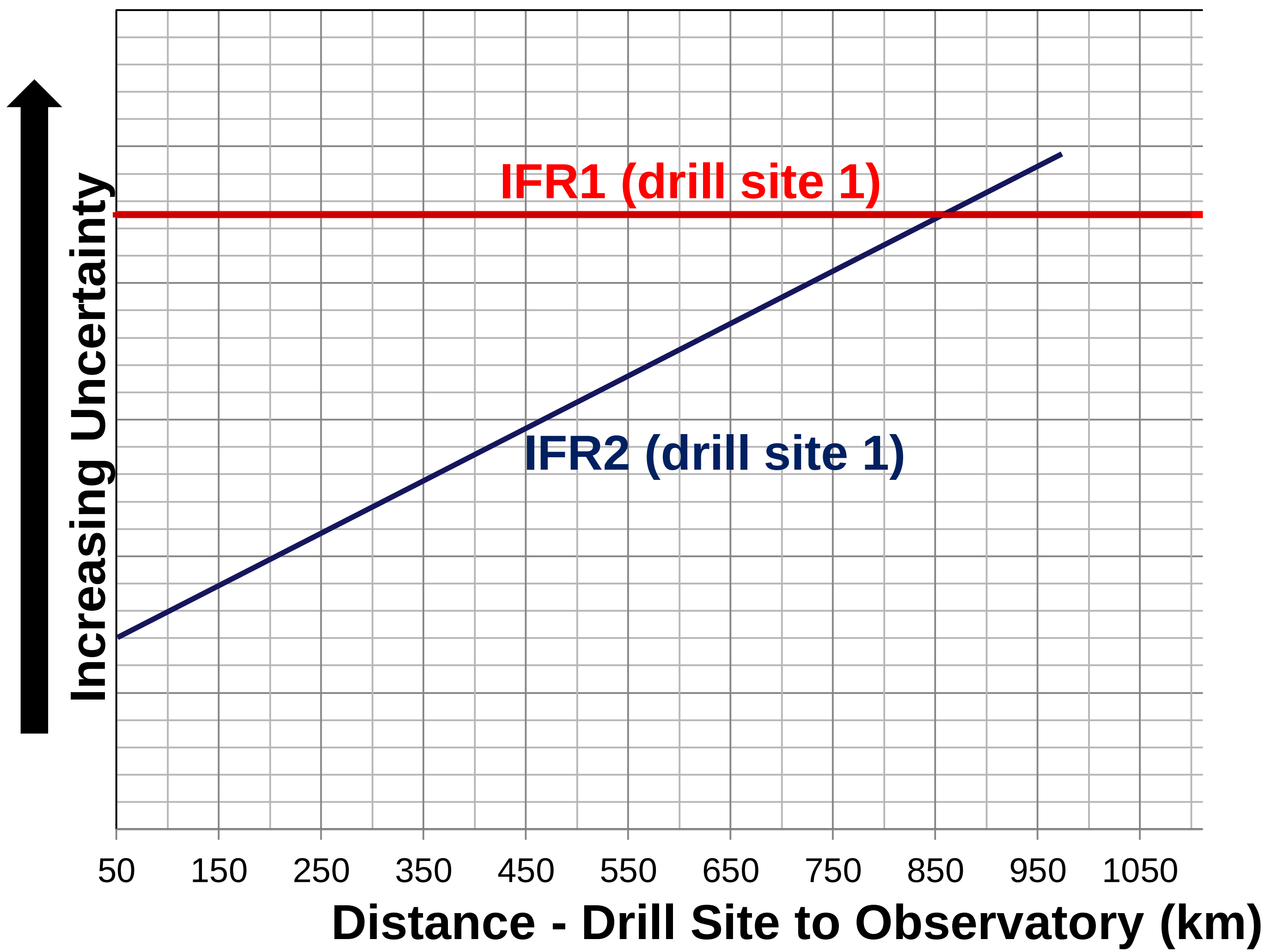


Including more sources of the Earth's magnetic field

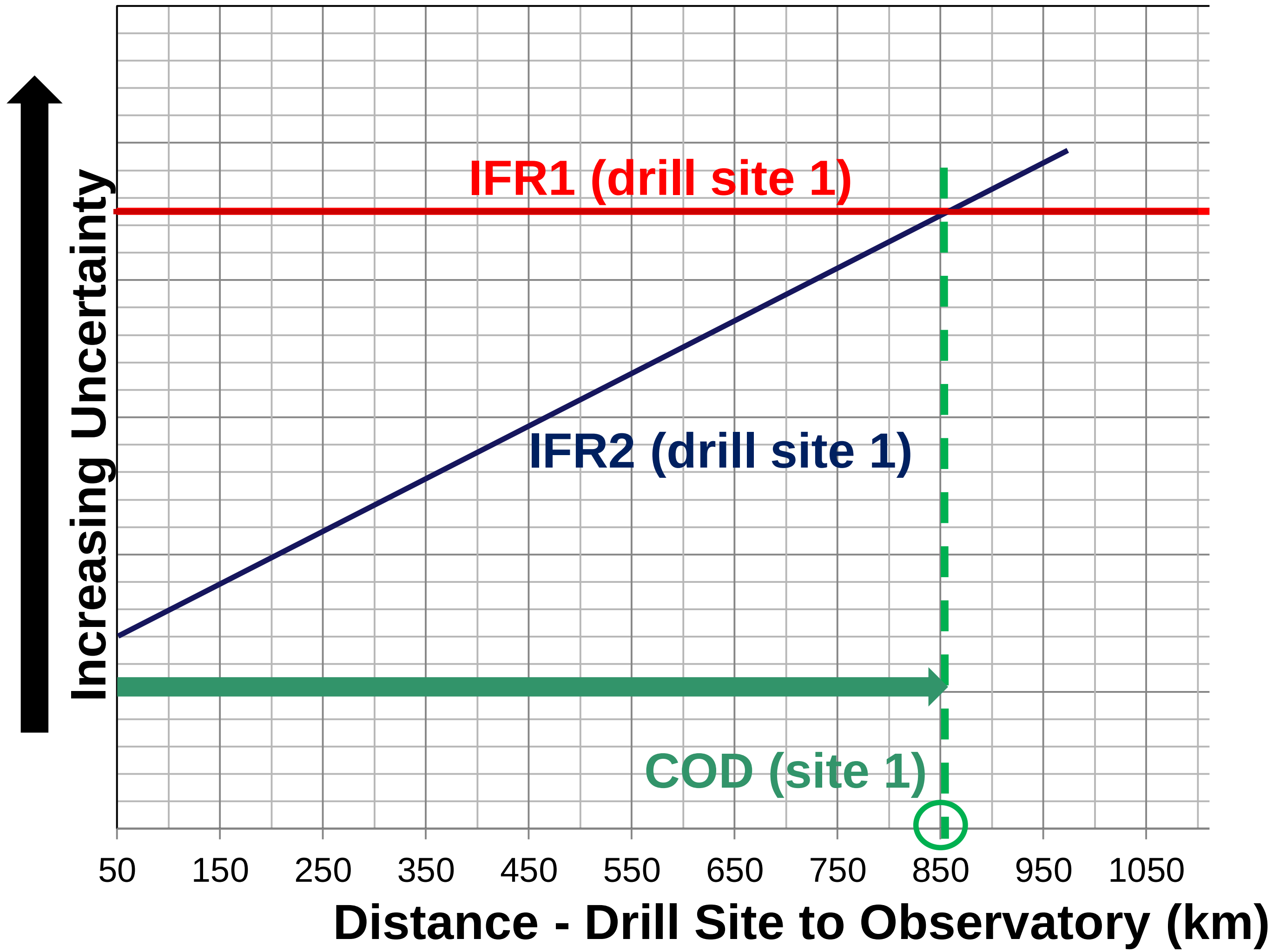
- Reduction in uncertainty

How much of a reduction – how do you know ?

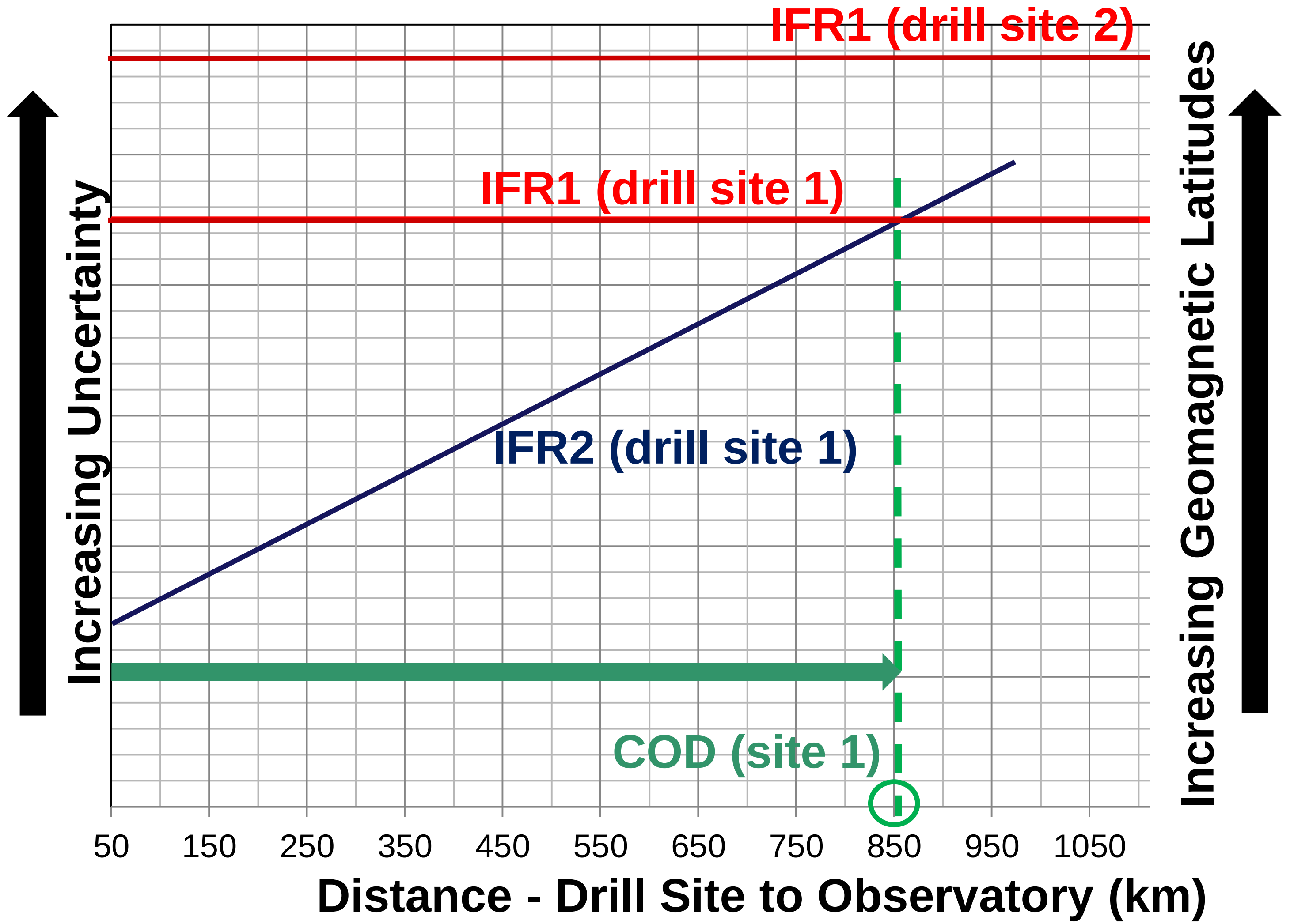
Schematic to demonstrate the problem



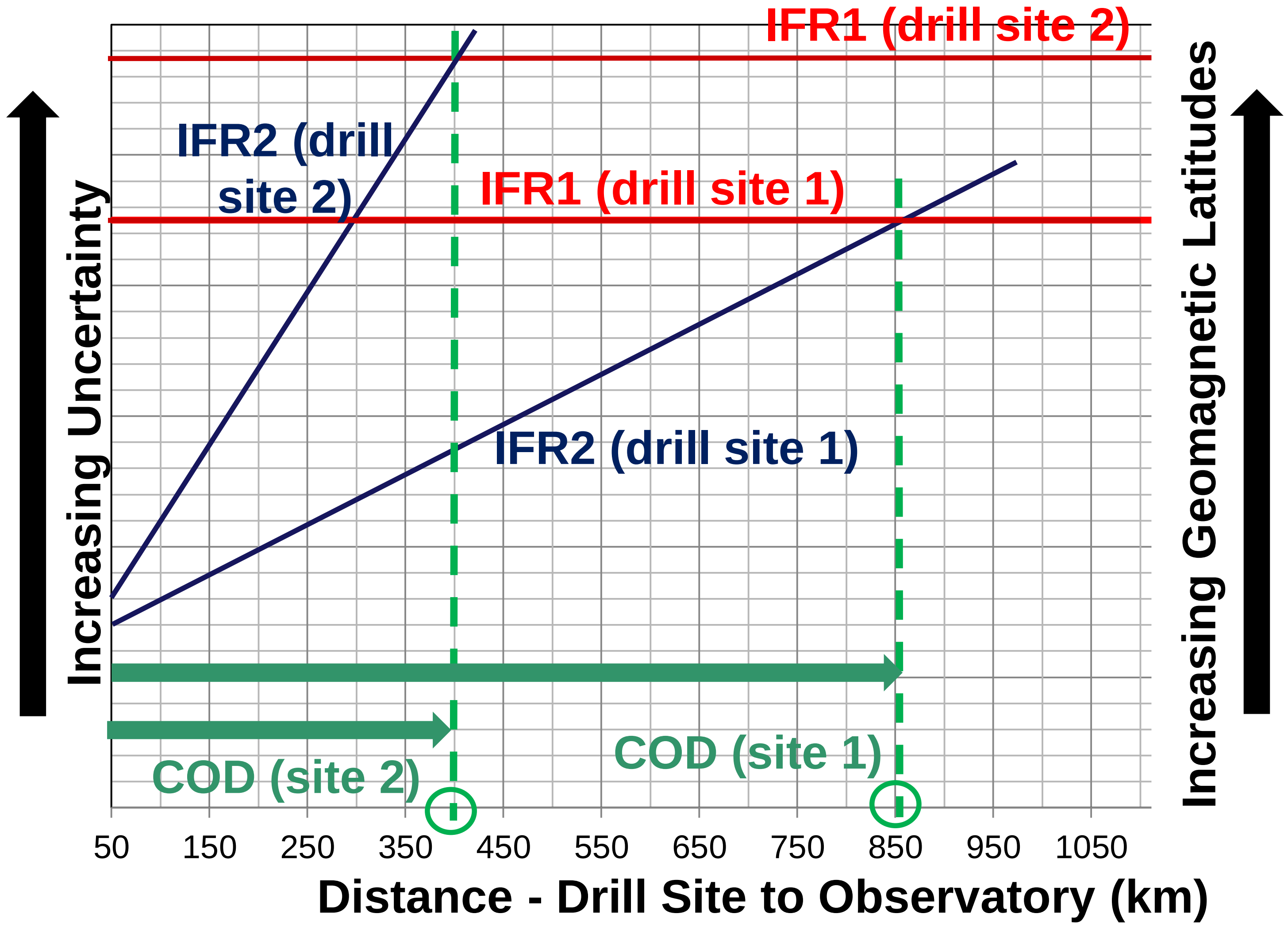
Schematic to demonstrate the problem

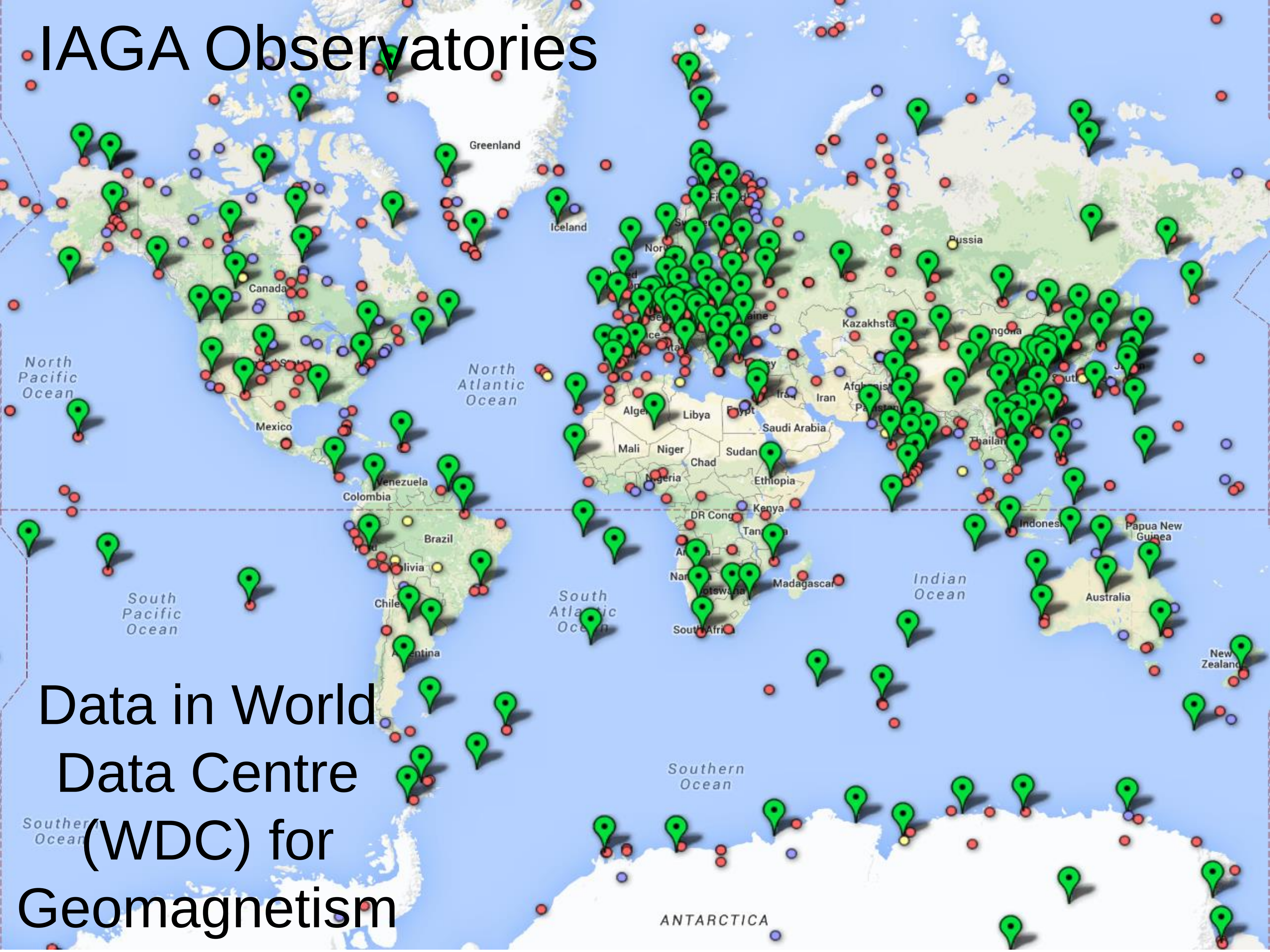


Schematic to demonstrate the problem



Schematic to demonstrate the problem

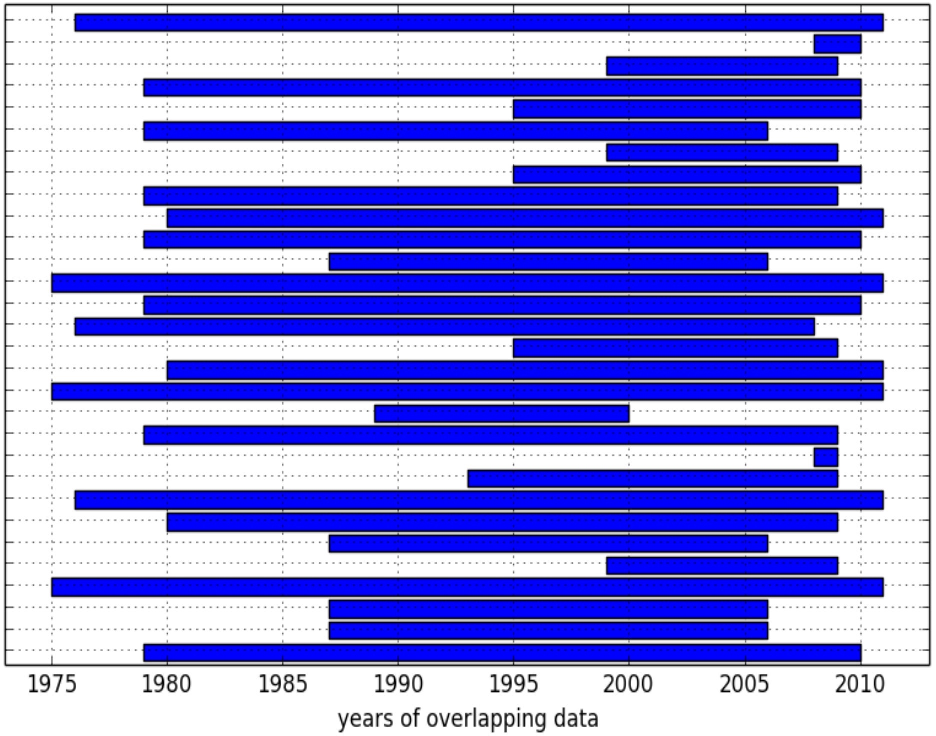


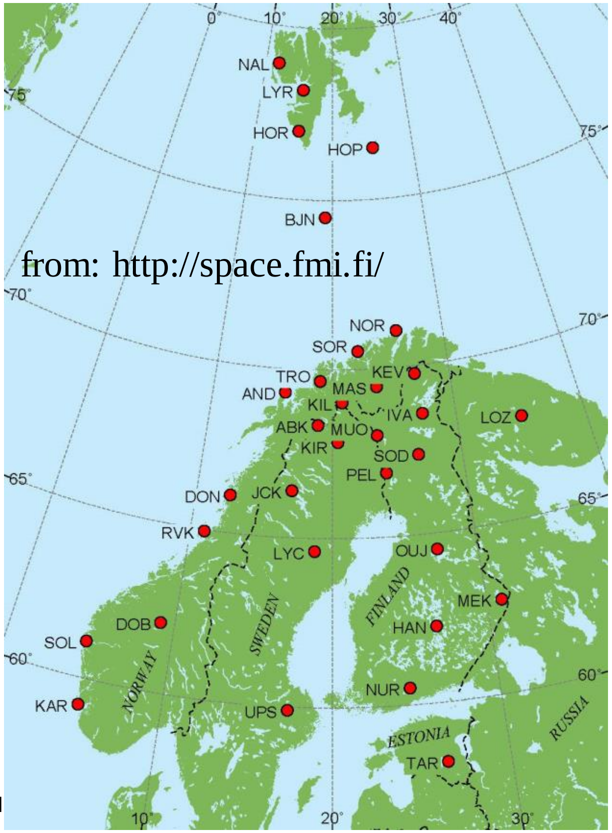

IAGA Observatories
Data in World Data Centre (WDC) for Geomagnetism
Greenland
Iceland
Russia
Canada
Kazakhstan
North Pacific Ocean
North Atlantic Ocean
Mexico
Libya
Saudi Arabia
Iran
Mali
Niger
Chad
Sudan
Ethiopia
Kenya
Venezuela
Colombia
Brazil
Madagascar
Indian Ocean
Papua New Guinea
Australia
South Pacific Ocean
South Atlantic Ocean
Chile
New Zealand
Southern Ocean
ANTARCTICA

Data Selection

We selected pairs of observatories from the world data centre (WDC) for Geomagnetism with:

- 58° <= abs(quasi-dipole latitude) < 75° (at 2013.9)
- <1000km great circle distance between them
- >=1 year of overlapping one-minute data





from: http://space.fmi.fi/

... and included variometer stations from the IMAGE network (same selection criteria)

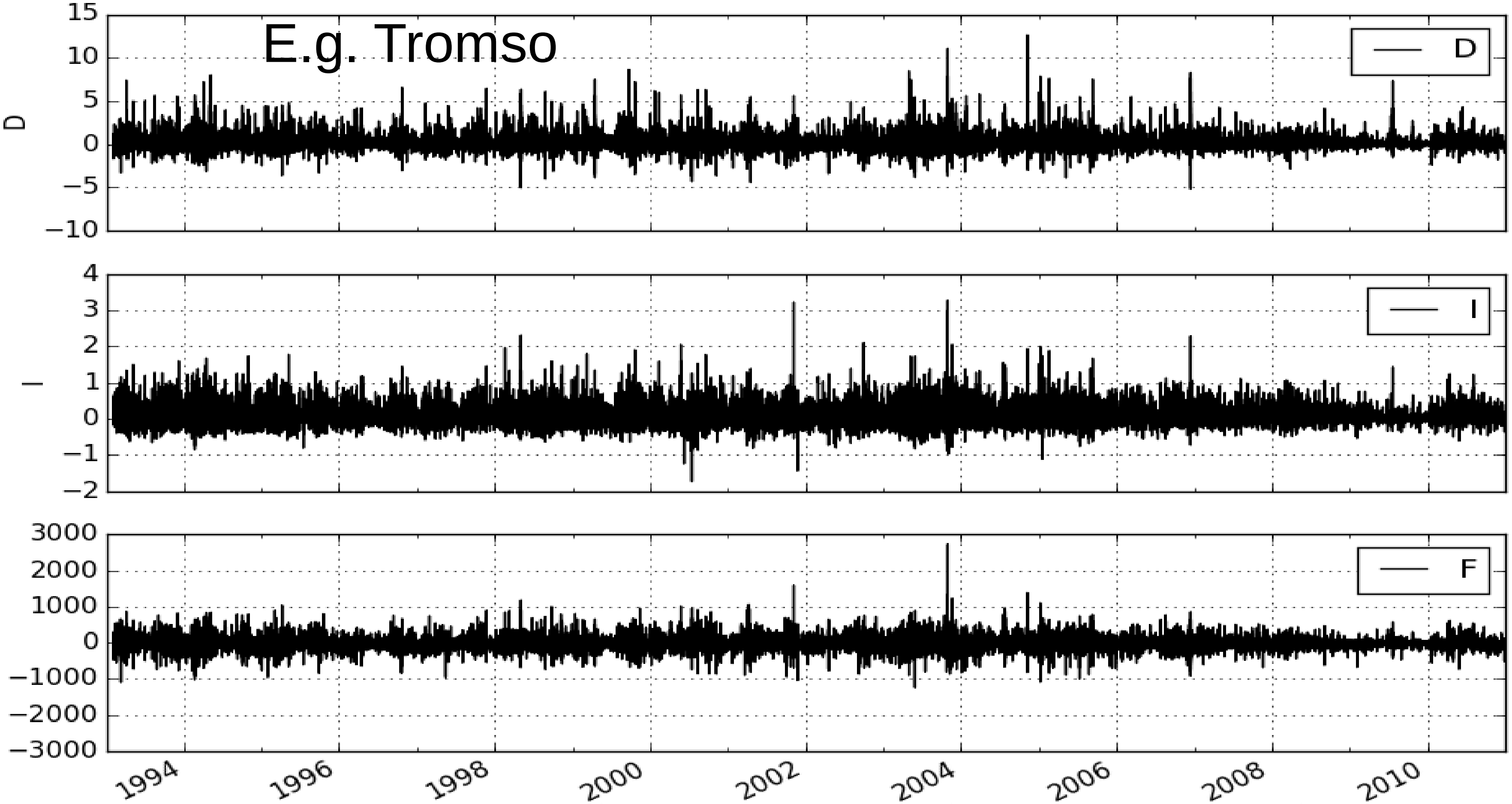
Following rejection of some stations - combined database of:

- **34 stations (originally 42)**
- **267 pairs of stations (originally 298)**
- **~3000 years of comparisons**

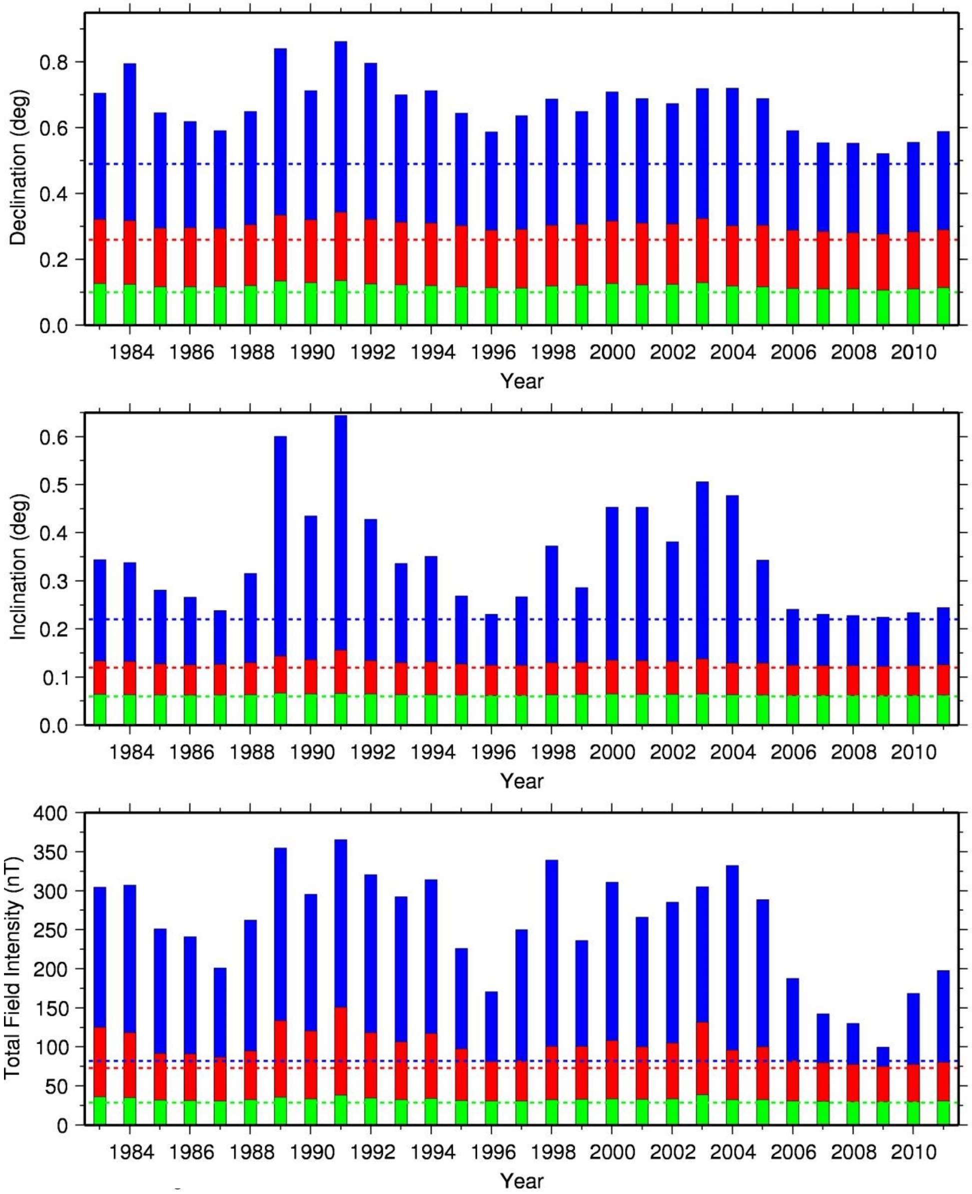
Data Processing

1. Separate the sources to find external variations
    - trends and offsets (internal) removed at all stations for all components
2. Compute one-minute residuals between all paired stations
3. Compute 99.7, 95.4 and 68.3 percentiles - 3σ, 2σ and 1σ equivalent

E.g. Tromso



Results Example: Lerwick all years



Annual uncertainties due to external field

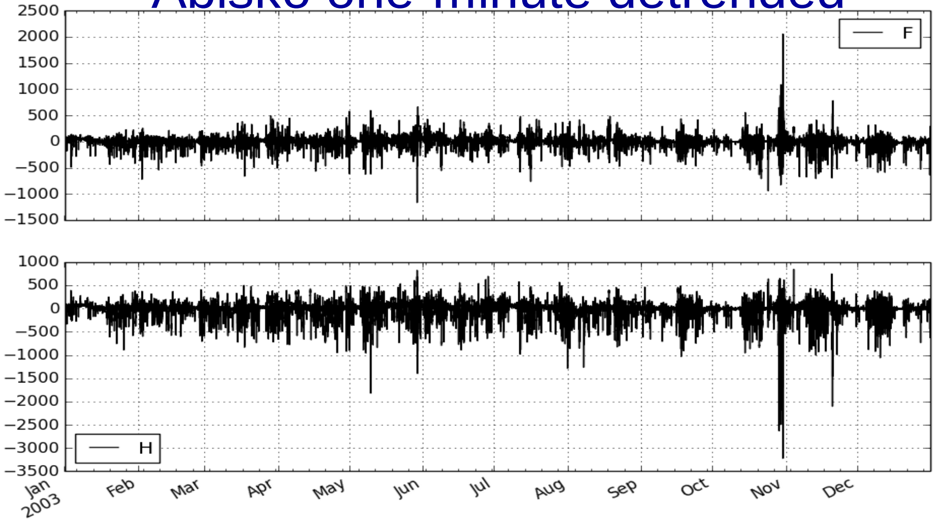
99.7% (3-sigma equivalent)

95.4% (2-sigma equivalent)

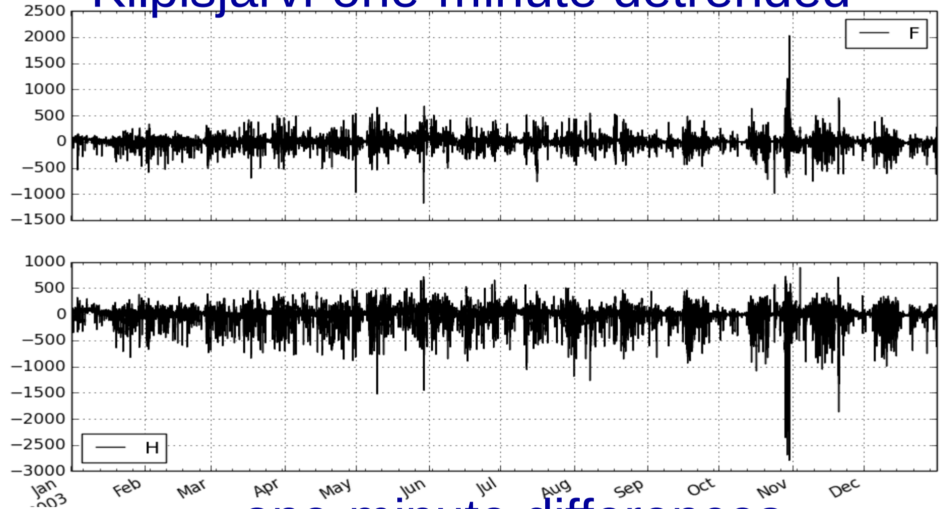
68.3% (1-sigma equivalent)

Results Example: ABK-KIL comparison (2003)

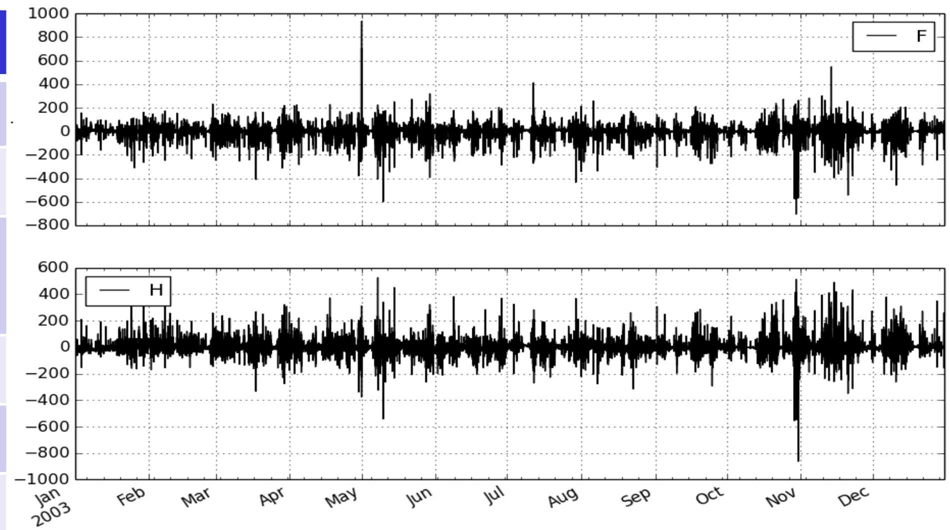
Abisko one-minute detrended



Kilpisjärvi one-minute detrended

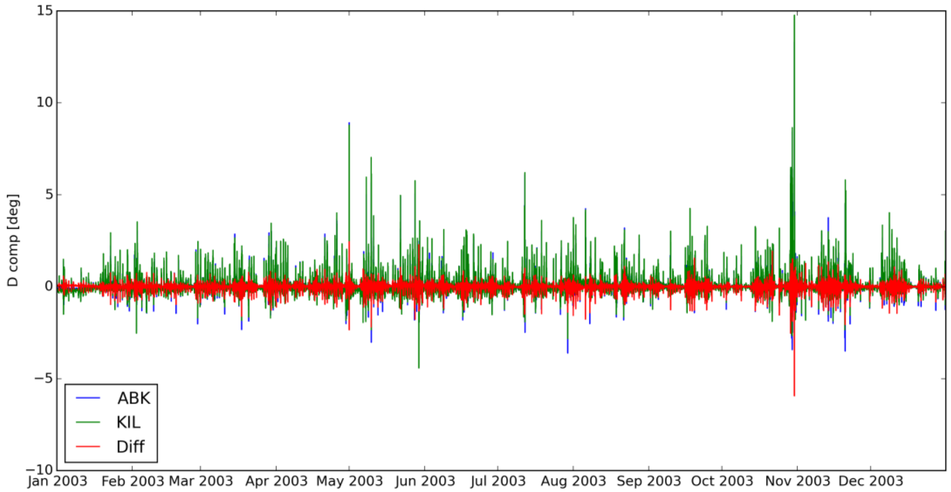


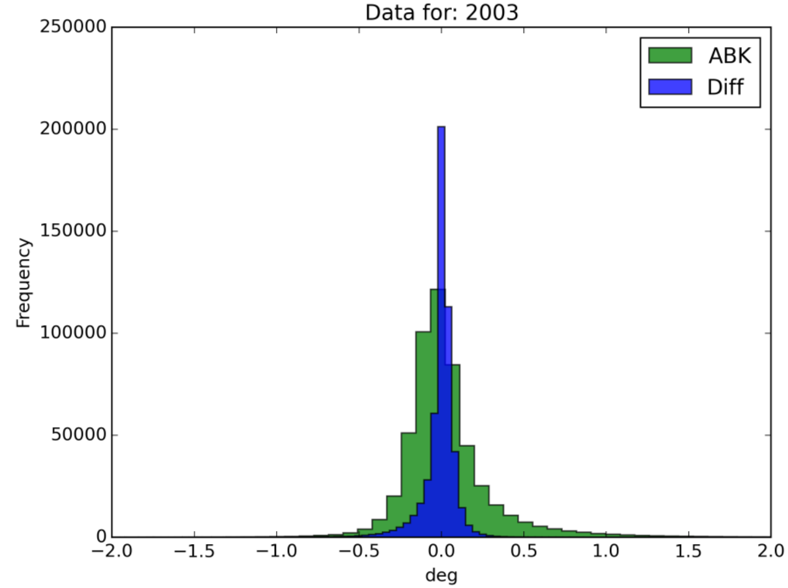
one-minute differences



	ABK	KIL
Latitude	68.35°	69.06°
GM Lat (quasi-dipole)	65.3°	66.0°
EW Distance (km)	79	
NS Distance (km)	77	
GC Distance (km)	110	
Overlapping years	1984-2006 (22 years)	

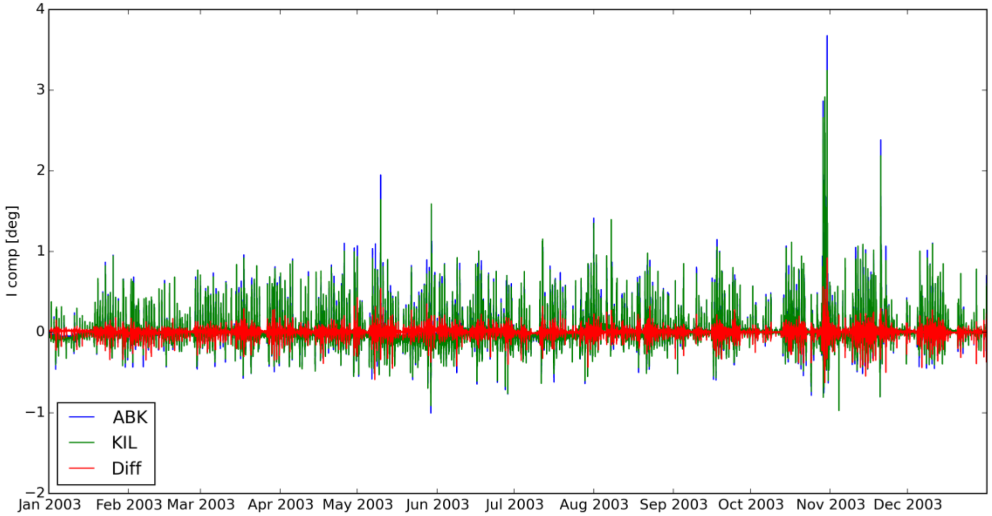
Results Example: ABK-KIL comparison (2003) Declination

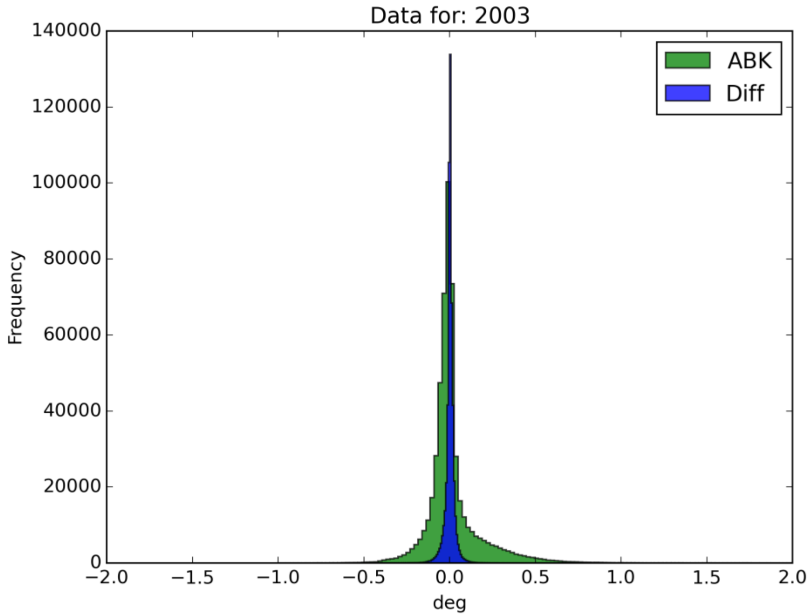




Dec (°) in 2003	1σ	68.3 %	95.4 %	99.7 %
ABK (detrended)	0.32	0.18	0.62	1.92
KIL (detrended)	0.37	0.22	0.75	2.19
Diff	0.11	0.06	0.22	0.68

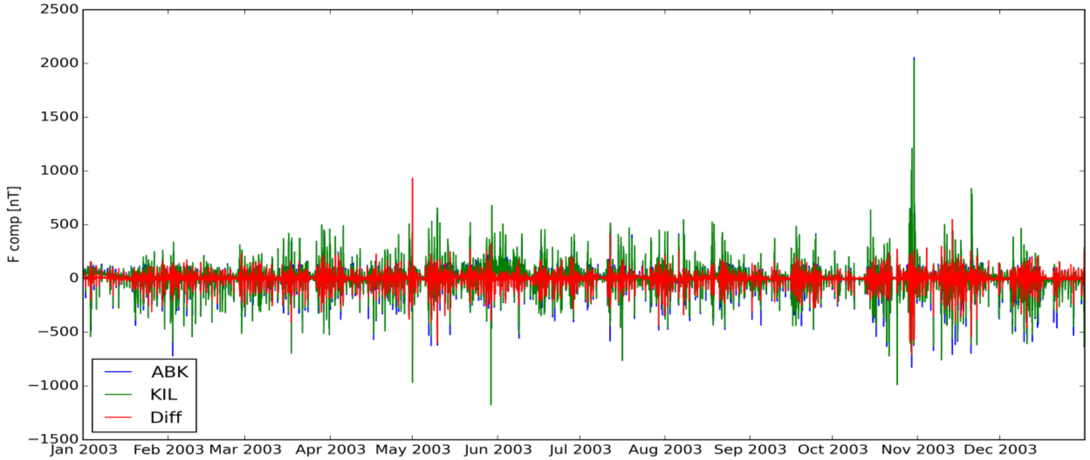
Results Example: ABK-KIL comparison (2003) Dip

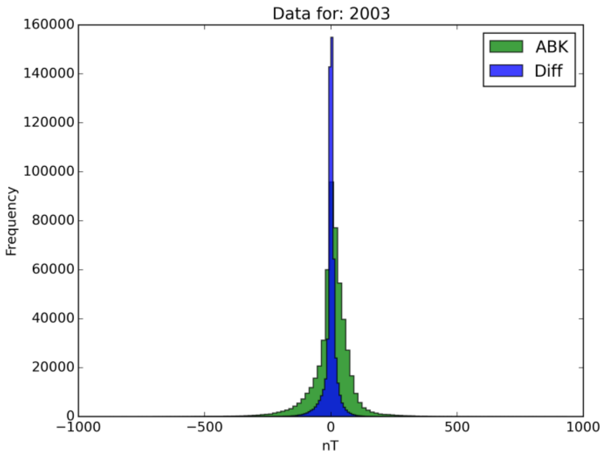




Dip (°) in 2003	1σ	68.3 %	95.4 %	99.7 %
ABK (detrended)	0.16	0.08	0.36	0.84
KIL (detrended)	0.16	0.09	0.36	0.81
Diff	0.03	0.02	0.06	0.17

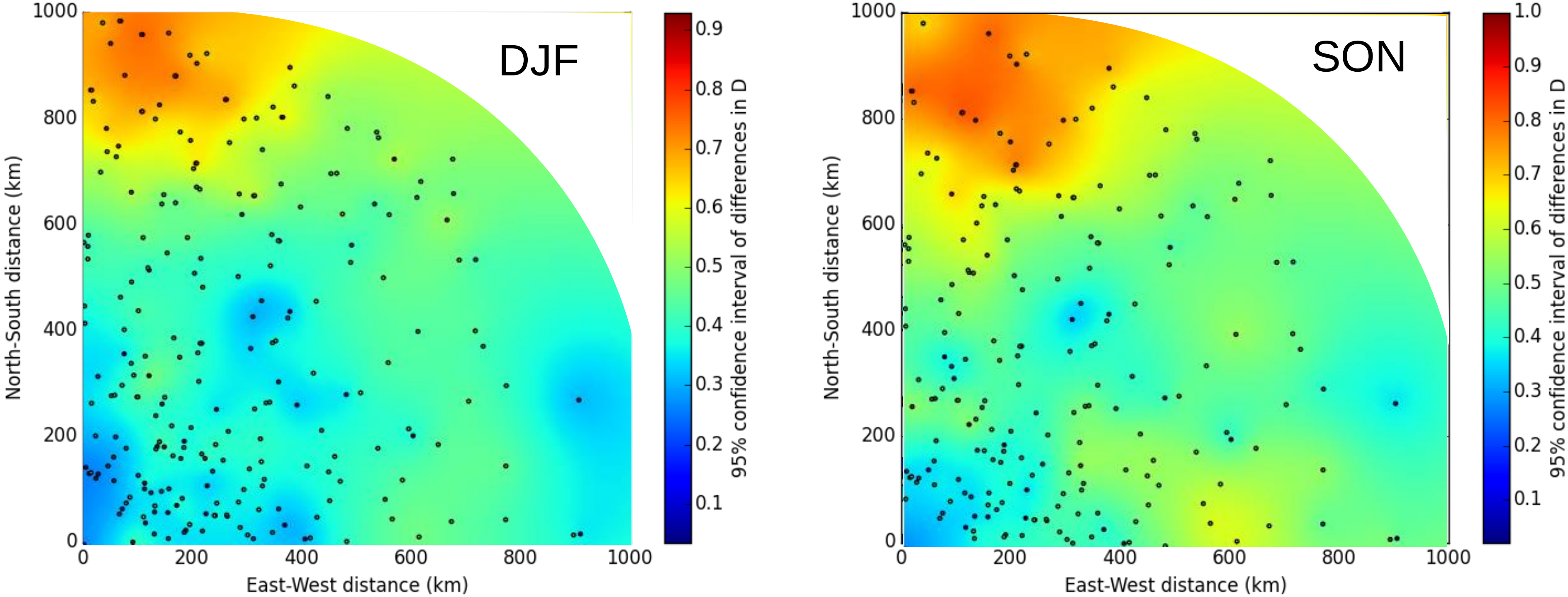
Results Example: ABK-KIL comparison (2003) **B** Total



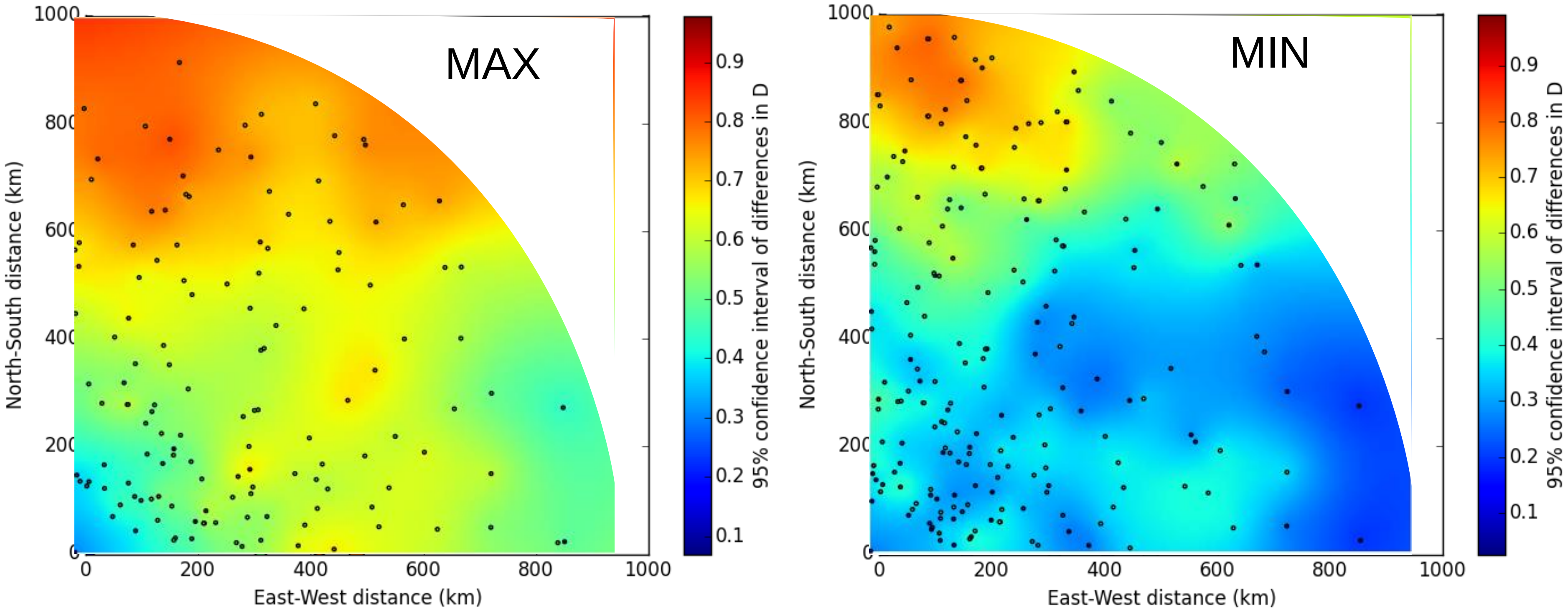


B Tot (nT) in 2003	1σ	68.3 %	95.4 %	99.7 %
ABK (detrended)	76	51	163	412
KIL (detrended)	78	48	171	426
Diff	28	12	63	167

Results Example: Seasonal Differences Declination

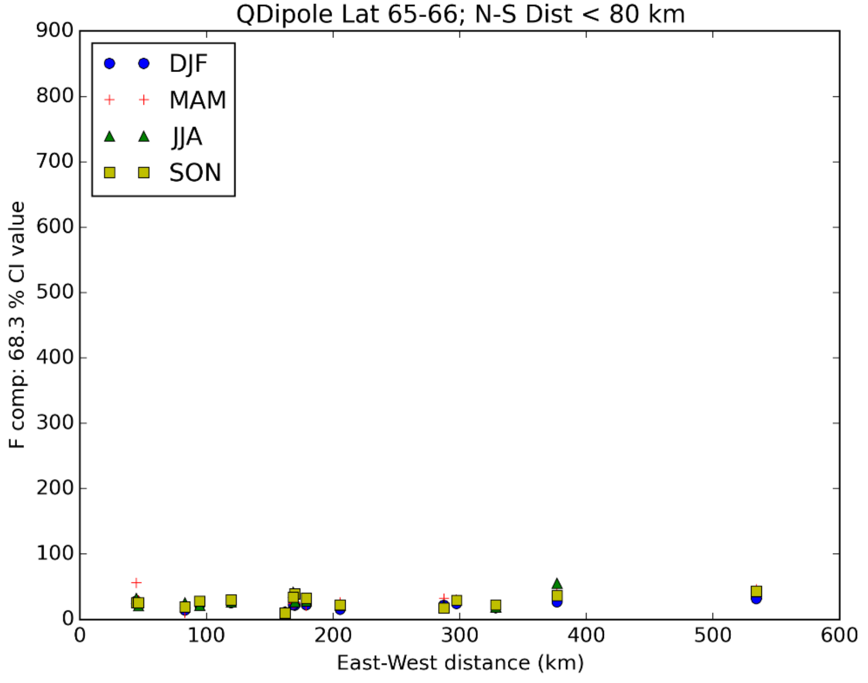


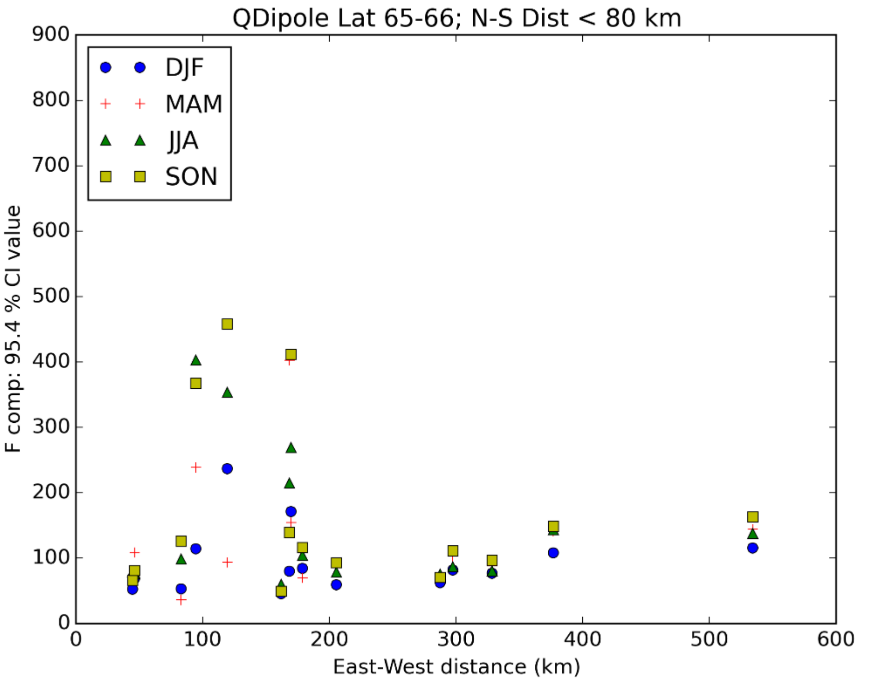
Results Example: Solar Cycle Differences Declination

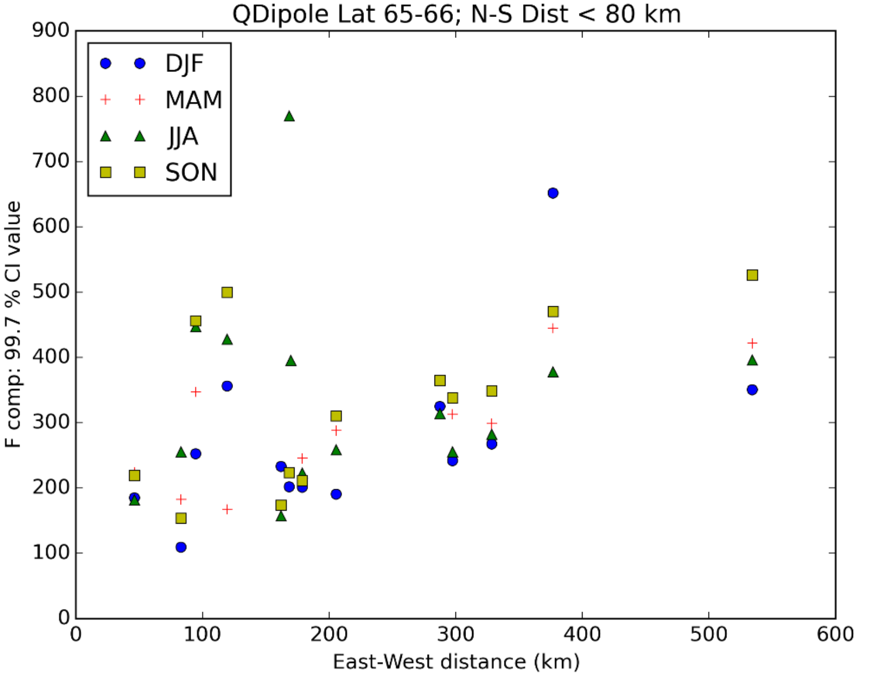


Results Example: **B** Tot

Quasi dipole latitudes 65-66° and N-S distance < 80km

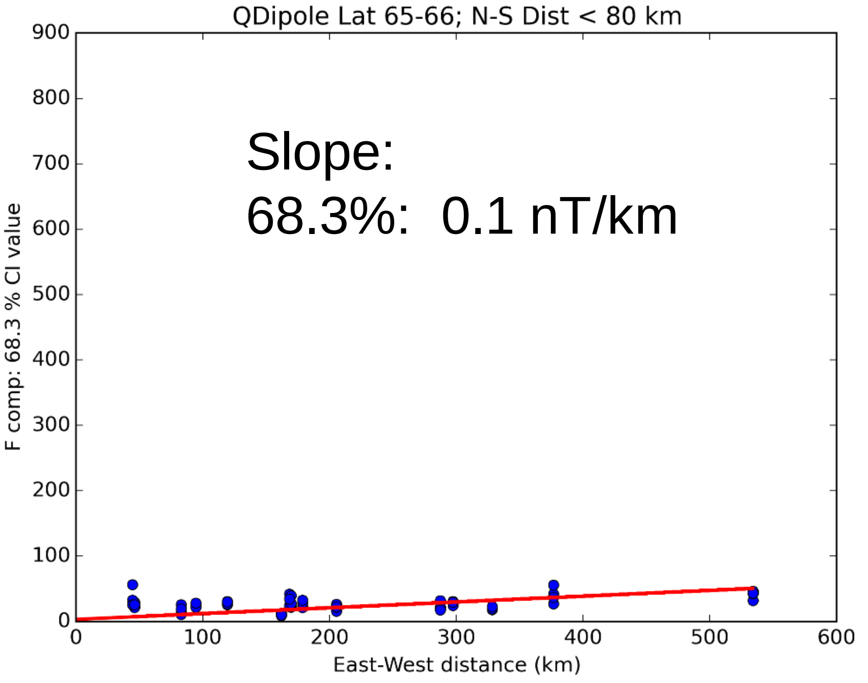




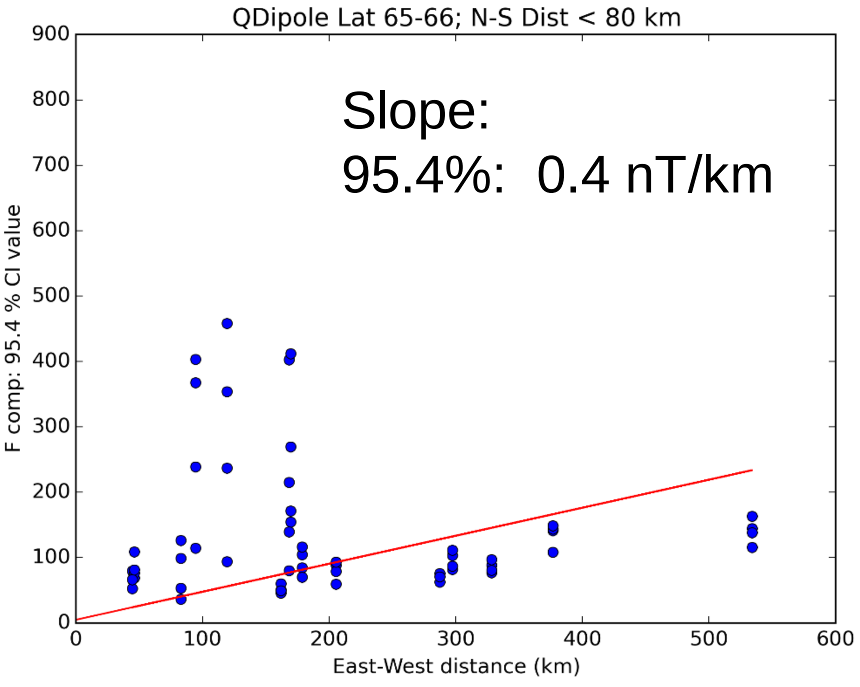


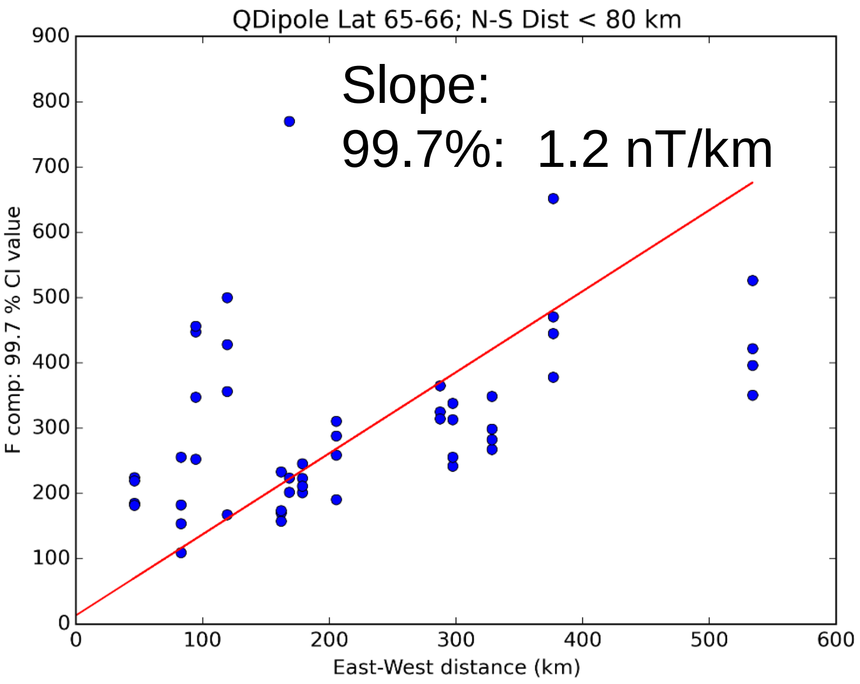
Results Example: **B** Tot [Linear Fit]

Quasi dipole latitudes 65-66° and N-S distance < 80km



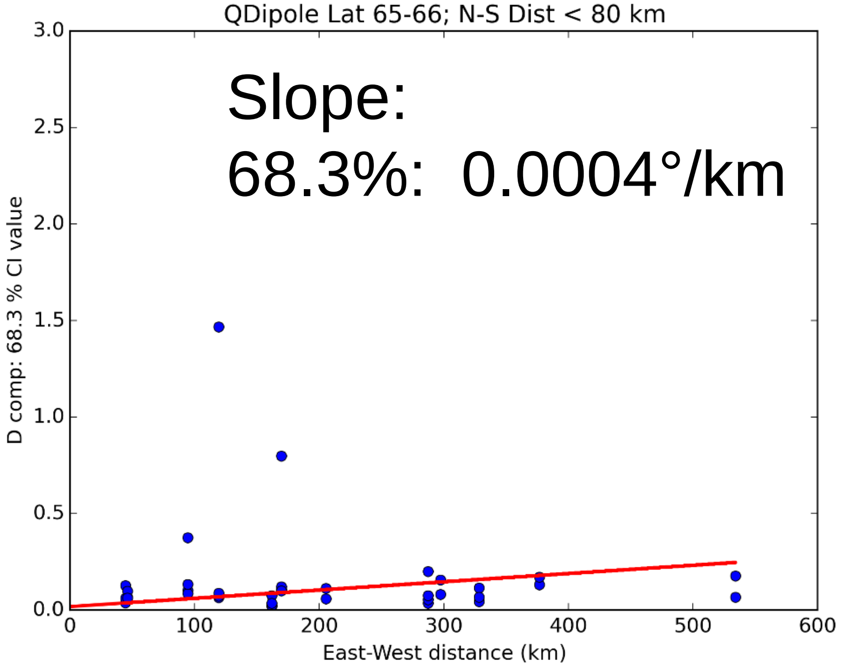
Note: slopes are indicative only

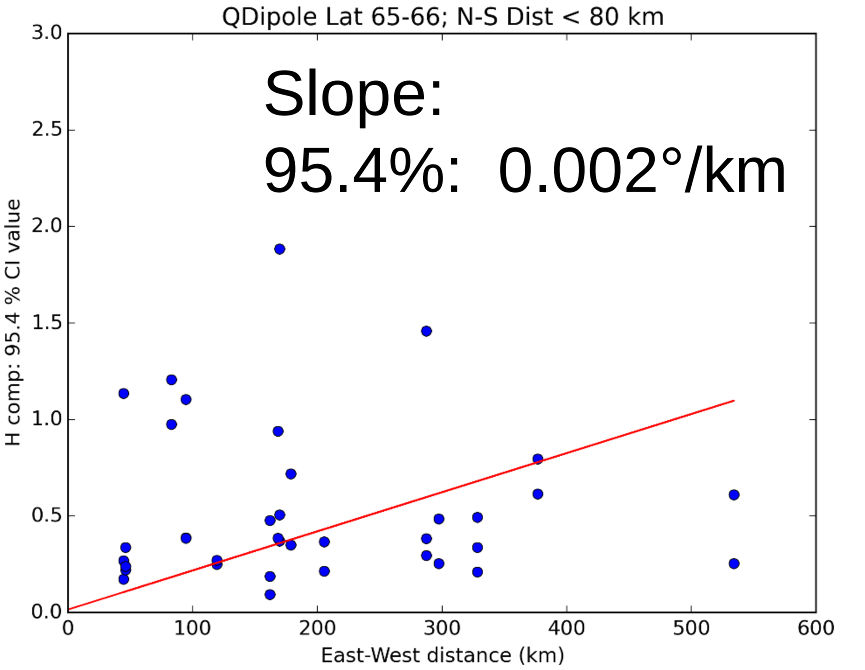


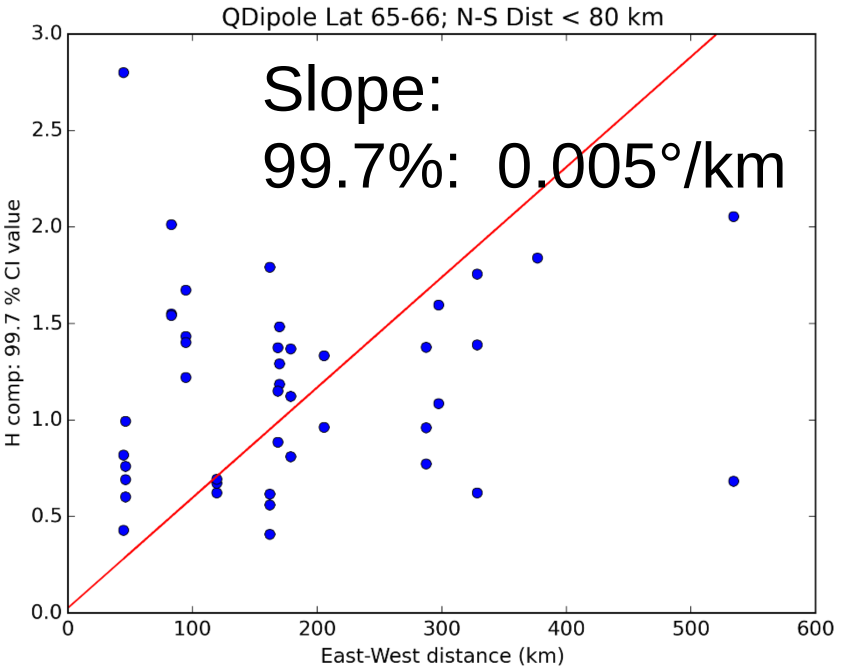


Results Example: Dec [Linear Fit]

Quasi dipole latitudes 65-66° and N-S distance < 80km







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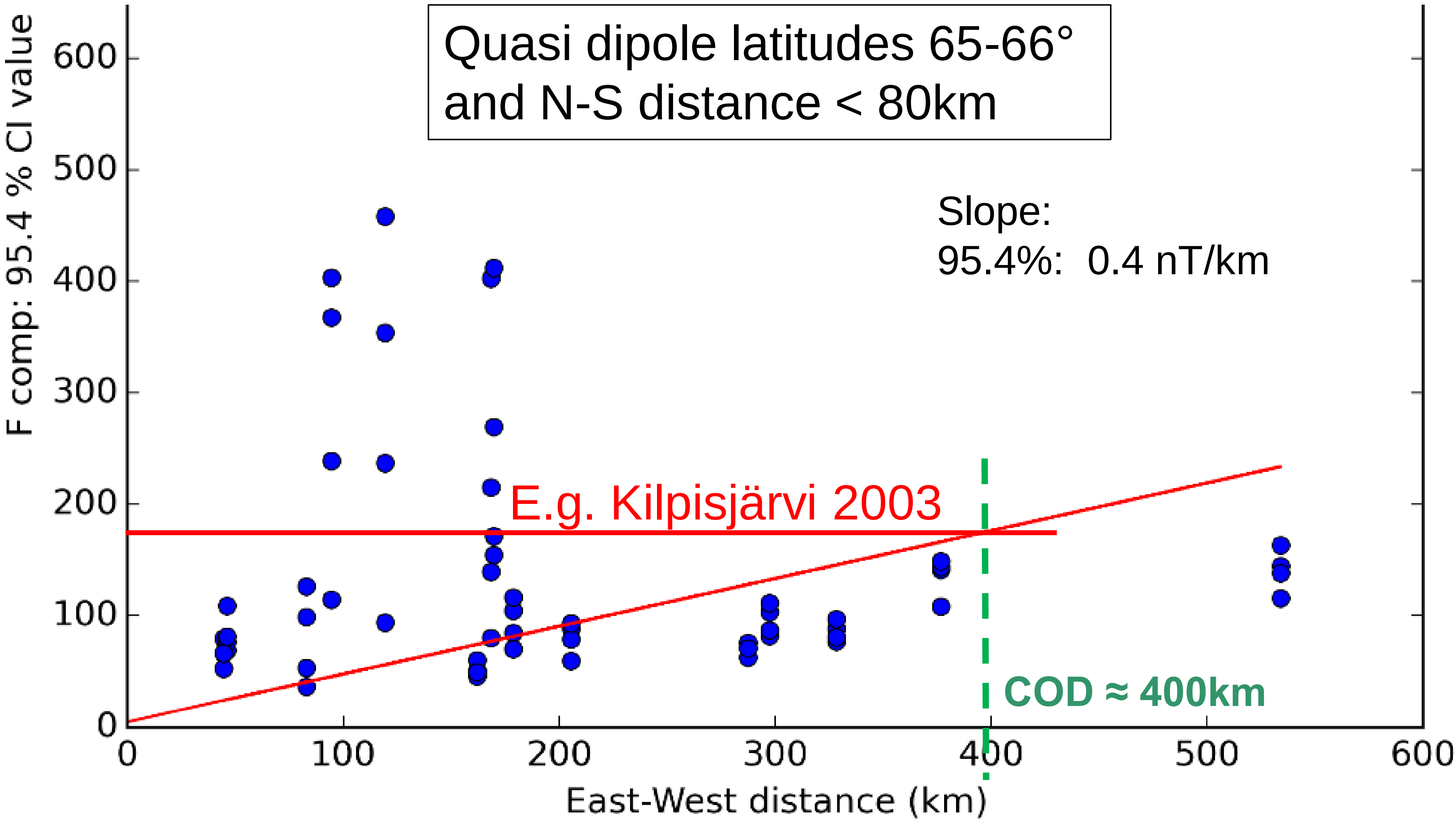
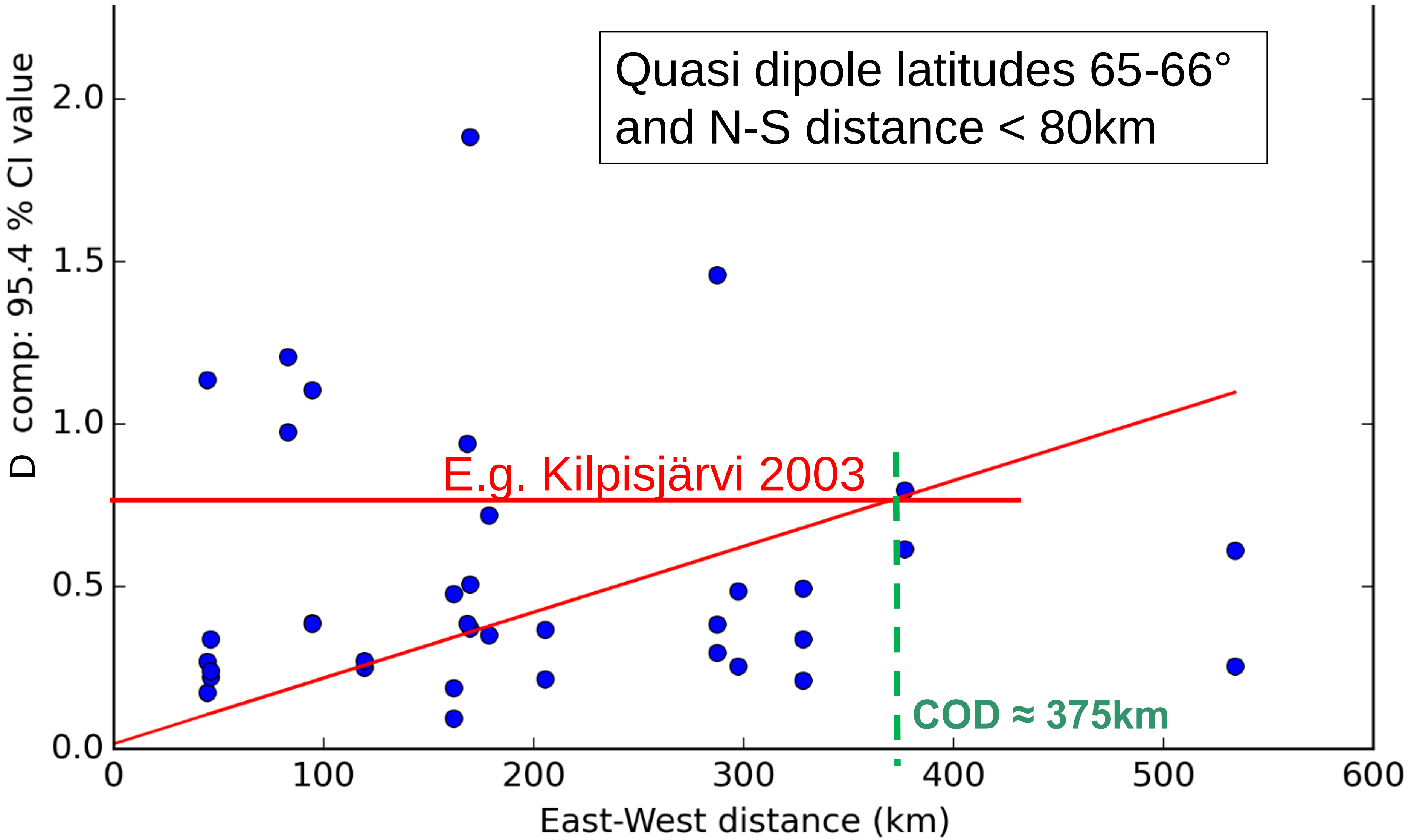
Original Demo and Example Results

B Tot [Linear Fit]



Original Demo and Example Results

Dec [Linear Fit]



Conclusions

- Confidence limits for the differences between example stations are significantly less than those for the external field variations (true even during geomagnetically active years)
- Non-Gaussian distribution of the variations and the differences between stations is clearly demonstrated
- The COD for IFR2 high latitude observatories is greater than previously thought
- Results show (as expected) solar cycle and seasonal variations
- A data set has been established that will be extended (both spatially and in time)
- More robust results should be possible by including more stations and with further analysis to detect and remove any clear outliers

Acknowledgements

We would like to thank:

- all of the institutes who run and maintain magnetic observatories and submit data to the WDCs and to INTERMAGNET; and

- all of the institutes who contribute to and maintain the IMAGE magnetometer array