59th General Meeting
17th & 18th of April 2024
Glasgow

Wellbore Positioning Technical Section

The Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA)

Assessing the absolute and relative accuracy of magnetic variometers compared to observatory IFR2

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Speaker Bio

- Scientist at British Geological Survey
- 15+ years in geomagnetism
- PhD, Univ. Edinburgh (2009)
- Specializes in main field modelling and forecasting, space weather, crustal field modelling
- Has installed *many* variometers since 2018

Background

- BGS typically advise that use of INTERMAGNET-standard observatory data with its high level of quality control and magnetic cleanliness is the best method to ensure that the ISCWSA *uncertainty* requirements for IFR2 are correctly met
- ISCWSA Gaussian 1-sigma uncertainties are: 0.1° in Dec, 0.05° in Inc and 50 nT in F

- Can we provide IFR2 values on land to support directional drilling using 'rigside' variometers?
- As an experiment, three sites in the UK which have variometer data for >15 months were examined as potential 'rigside' variometers using IFR2 values created from observatories: LER, ESK and HAD
- This study analyses the behaviour and uncertainties arising from use of observatory versus uncontrolled variometers

What is an observatory?

- Remote, magnetically quiet location
- Continuous
- Broadband (second to centuries)
- Absolute Accuracy (0.1 in 50000nT)
- Weekly manual measurements to control instrumental drift and QC angular values
- Formally published

Prudhoe Bay, Alaska

Lerwick, Shetland

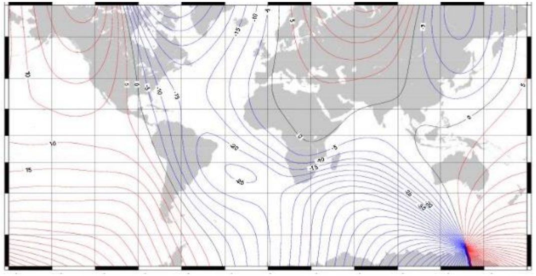
What is a variometer?

- Narrower-band (second to hours)
- Relative precision (0.1 nT)
- Continuous (1 Hz)

- **Not absolute** measurement of field magnitude or direction
- Strong temperature sensitivity
    - Burial or active climate control
- Requires initial calibration (at observatory)
- Cheaper sensors have larger uncertainties
    - Can have hysteresis memory (change in offset on system restart)

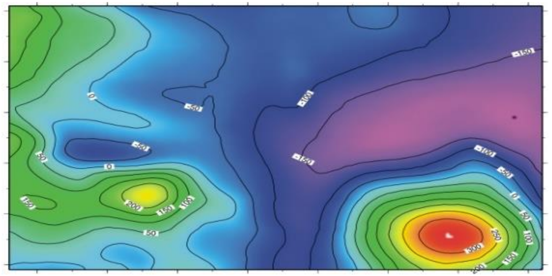
What is IFR2?

Including more sources of the magnetic field



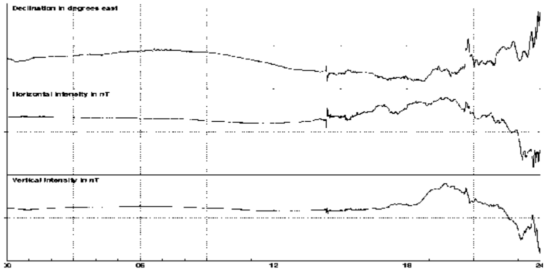
Core (or main) field

- ~95-97% from outer core
- Captured by global models



+ Crustal field

Local crustal anomalies in more detail along a well path



+ External field

Variations in time due to ionospheric and magnetospheric currents

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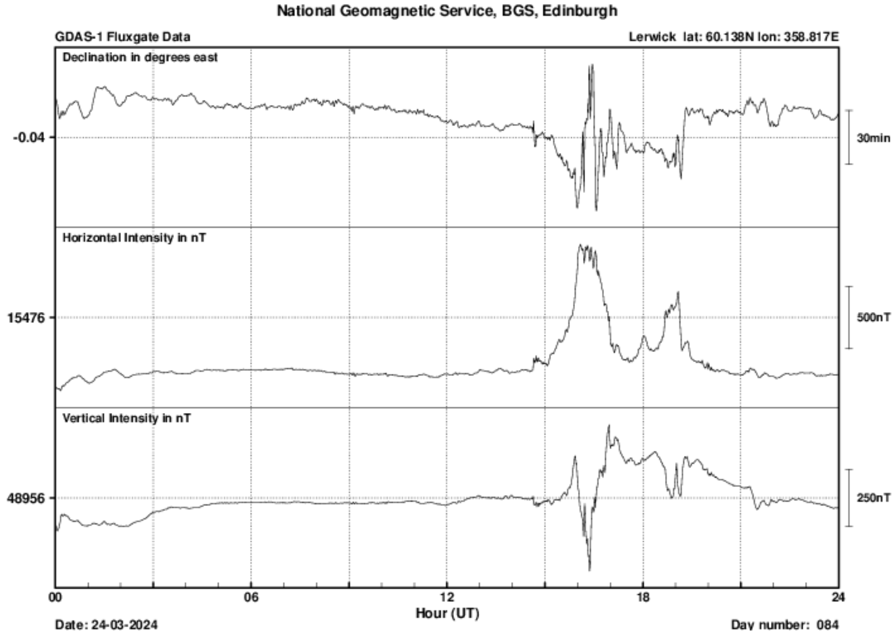
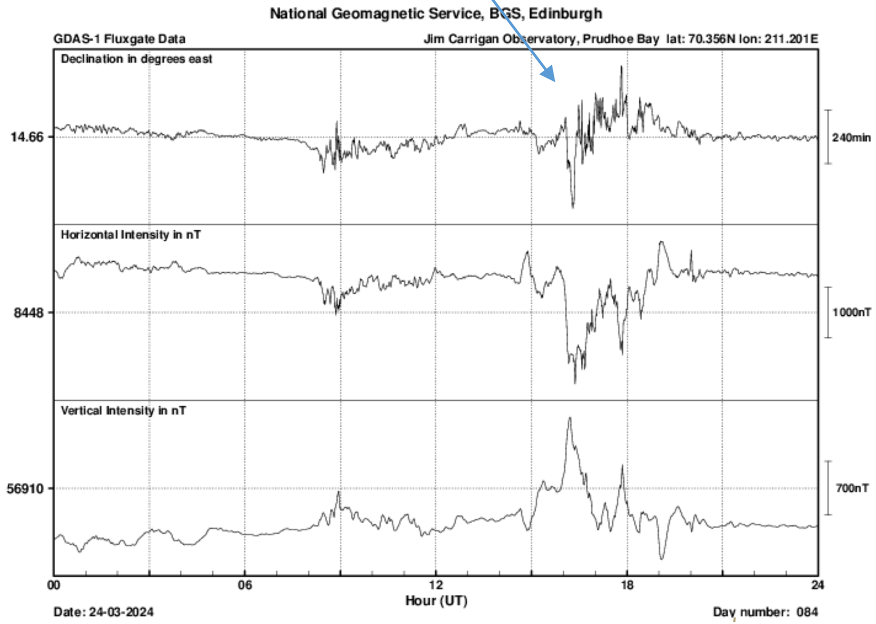
Largest storm of cycle 25: Kp8 on 24-Mar-2024

Compass swing of ~10˚



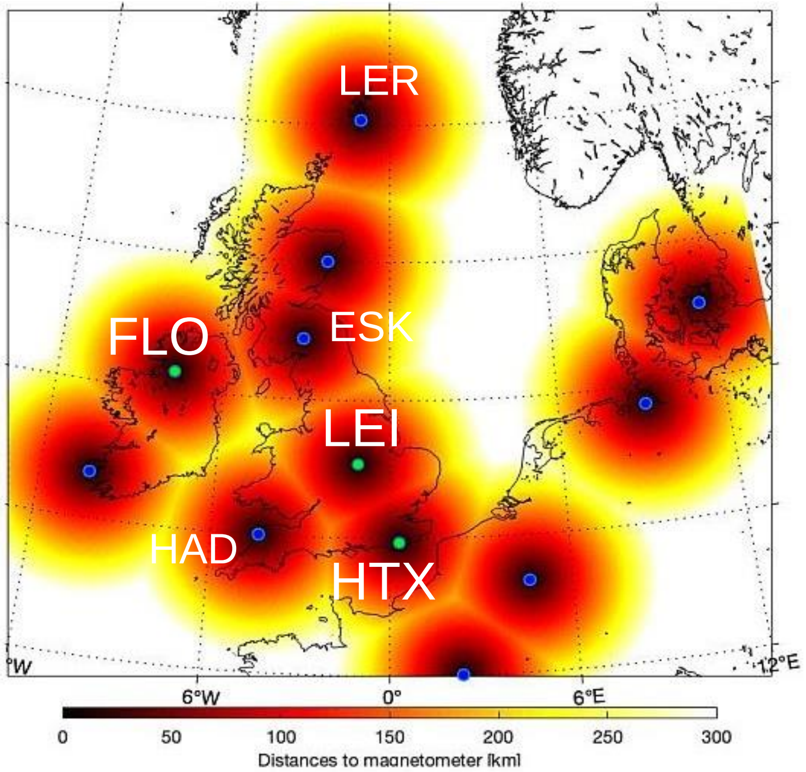


Study Dataset

1) Three long running INTERMAGNET-standard observatories

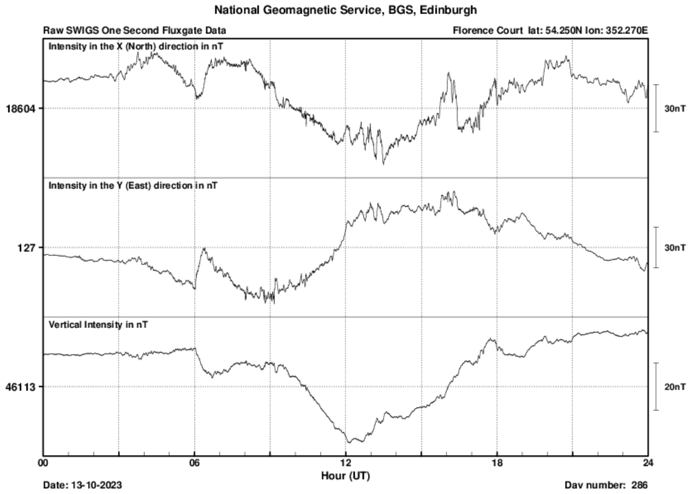
2) Three *variometers* for space weather monitoring have been running for around two years (mid-2022) at:

- Florence Court (Northern Ireland) [FLO]
- Market Harborough (Leicestershire) [LEI]
- Herstmonceux (Sussex) [HTX]



Variometers

- Each site consists of a Sensys 3-axis fluxgate magnetometer attached to a 24-bit EarthData-50 digitizer recording at a cadence of 1 Hz
    - In FLO and LEI, the systems are standalone in a field with batteries and solar panel for power with data transmitted to BGS via 4G/LTE network
    - HTX is within the grounds of the BGS Satellite Geodesy Facility and has a continuous wired power supply and internet connection
- Each variometer has its own unique environmental circumstances which can be used to investigate how a field-deployed variometer might be expected to behave
- Data are viewable at: https://geomag.bgs.ac.uk/research/SAGE/variometer_data.html



HTX

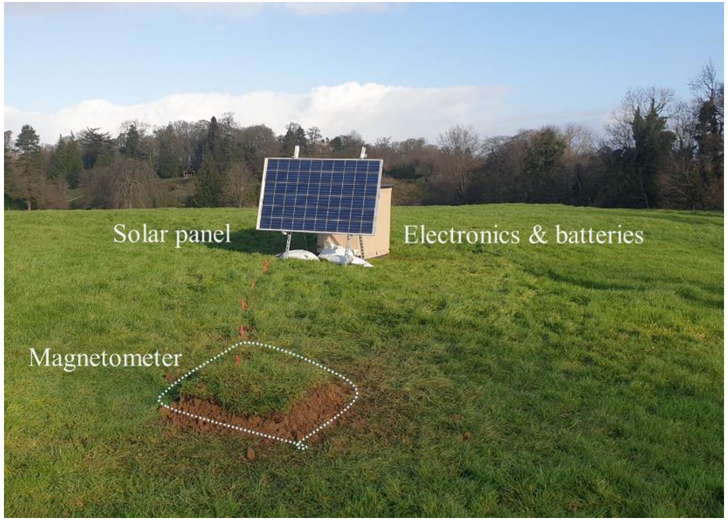
- HTX magnetometer is a *semi-permanent* installation close to buildings in the Herstmonceux estate
- Magnetometer is on a stable concrete mount and is correctly orientated and levelled
- *No control* over local manmade noise so the site suffers from regular spikes and occasional power cuts
- The site is also close to electrified railway lines
- Continuous noise 10-20 nT in the Z component

- Examine the effects of *continuous man-made noise and occasional large spikes* in the data

FLO

- Florence Court variometer is located in a remote site on the National Trust property in an enclosed field (livestock)
- Data are generally noise-free bar occasional (once per month) spikes
- After installation in Feb 2022, the magnetometer barrel in the ground **rotated** from magnetic East/North and **unlevelled** for vertical Z (probably animal-related)

- Investigate issues with *incorrectly orientated* sensors



LEI

- LEI magnetometer is in an arable field around 5 km south of a small town
- 400 m from nearest roads and buildings
- Generally high-quality site suffering only occasional undermined noise
- Wind damage caused bad measurements in Aug 2023
- Assume initial setup has not drifted or rotated since installation

- In theory, *the best-case scenario for a variometer*

Methodology

- Each site: FLO, LEI and HTX is set up as an *IFR1 site* using the standard BGS procedure using BGGM2023 and the 1963 UK aeromagnetic compilation
- An IFR2 site file for each variometer was created using:
  - FLO: ESK/LER
  - LEI: ESK/HAD
  - HTX: HAD
- The site files consist of minute values of D, I and F
- The full field 1 Hz variometer datasets were converted files to ASCII X, Y and Z values
- Using Python and pandas the variometer 1 Hz values are converted to D, I and F and then averaged to a simple minute mean
- The minute-mean values from the variometers are compared to the site file values

Variometer Data

1. Convert 1Hz native binary to unscaled ASCII format
2. Convert unscaled to scaled X, Y and Z (nT) using calibration factors
3. Convert to D, I and F and average to simple minute mean values

IFR2 Data

1. Create IFR1 setup
2. Cross check setup against aeromagnetic maps
3. Compute IFR2 Site File in D, I and F from observatory pairs

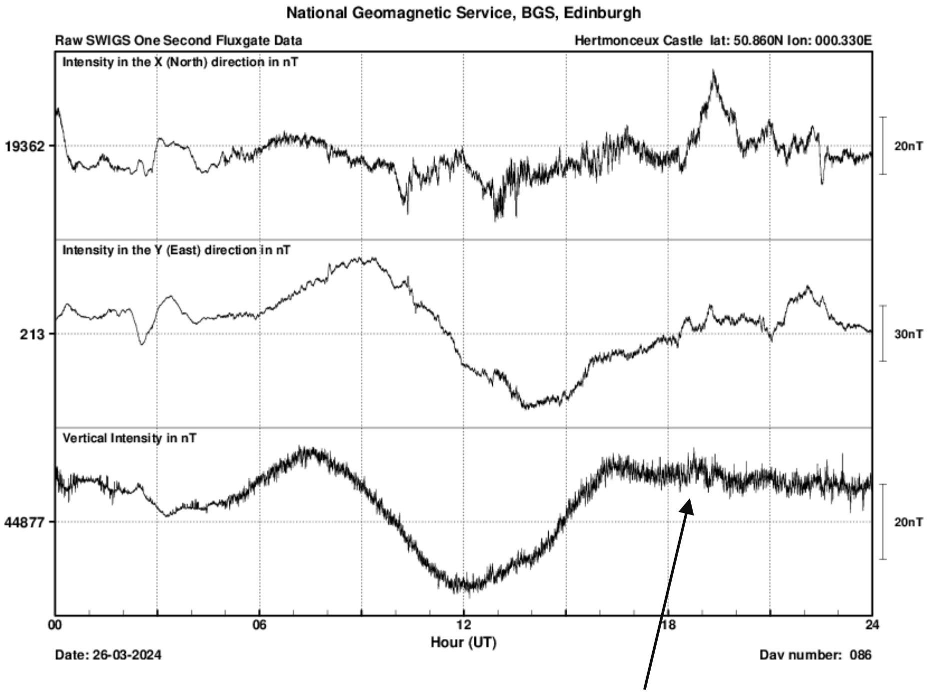
Compare minute means values for ~1 year of data

Results

- Analyse comparison in 3-month periods and over 15 months Jul-2022 to Sep 2023

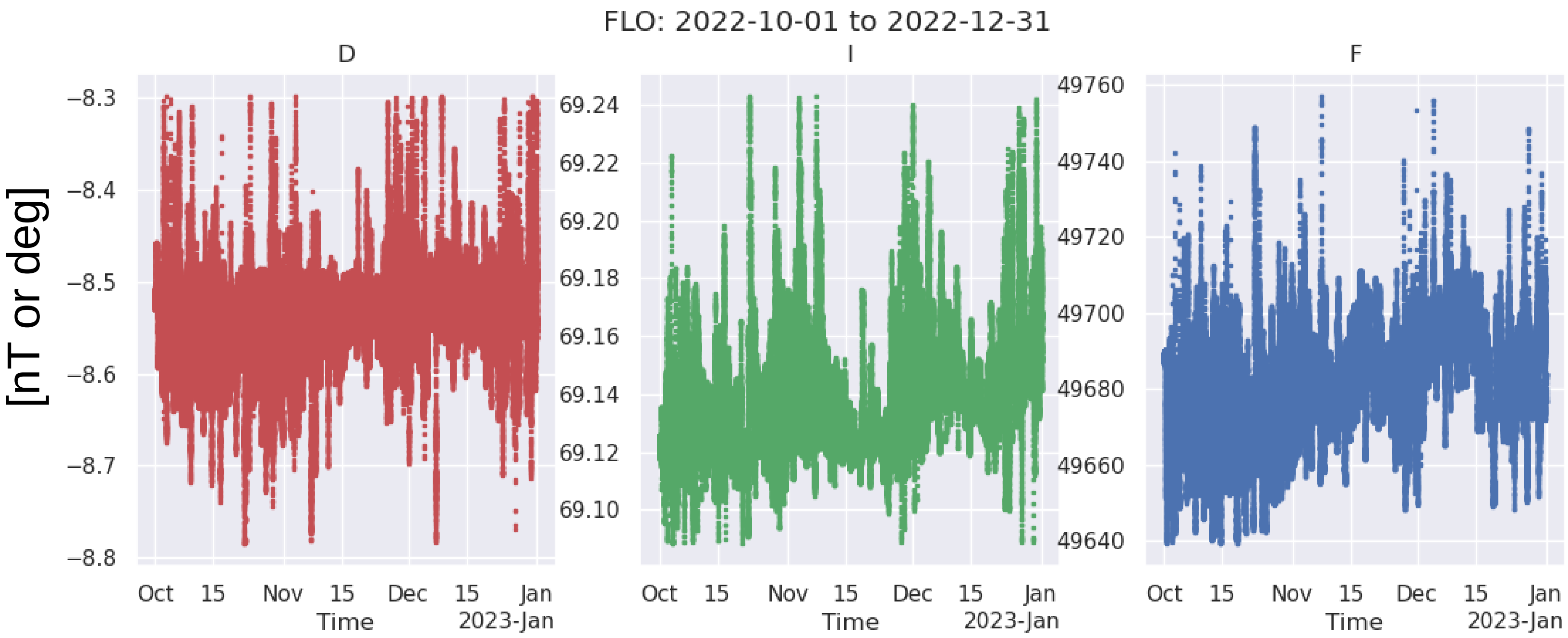
- IFR2 site files are complete
- Missing variometer data in some periods - so only existing data are compared

- Compute statistics

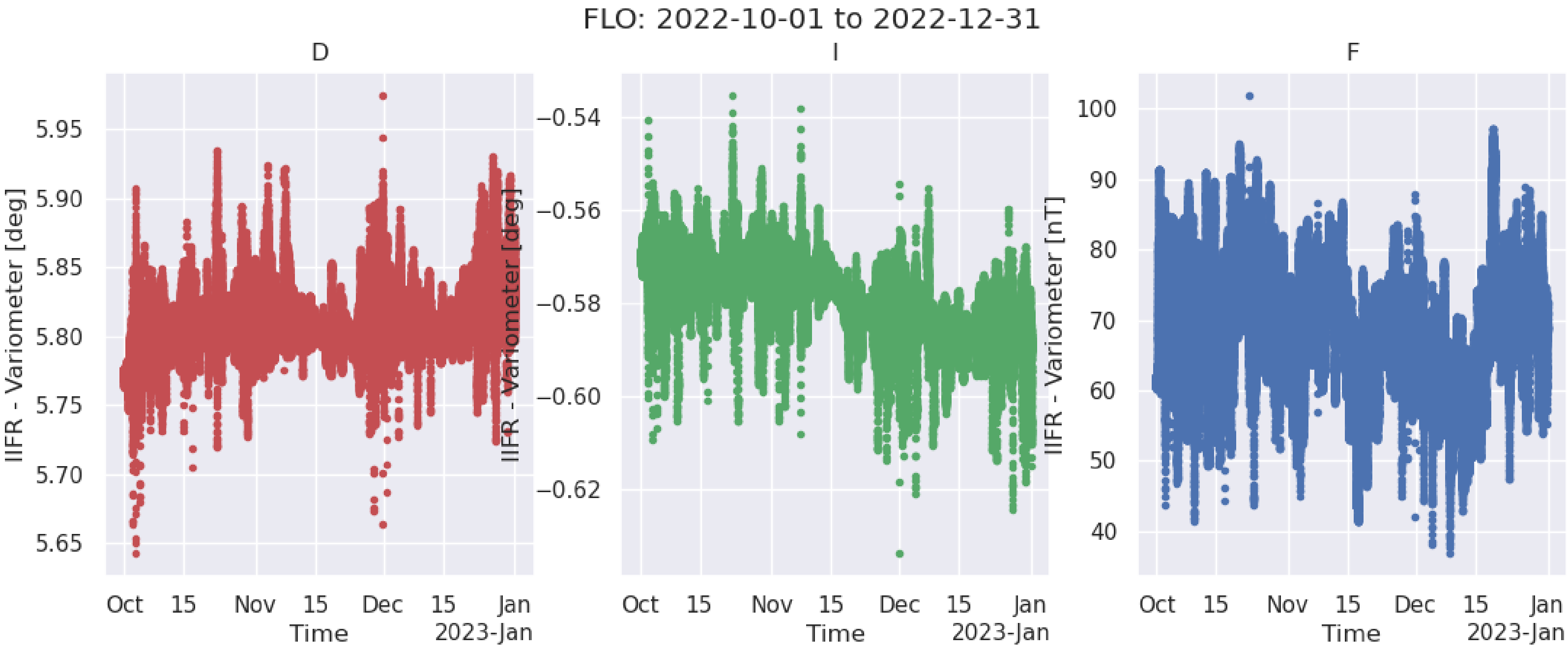


Example of railway interference in HTX

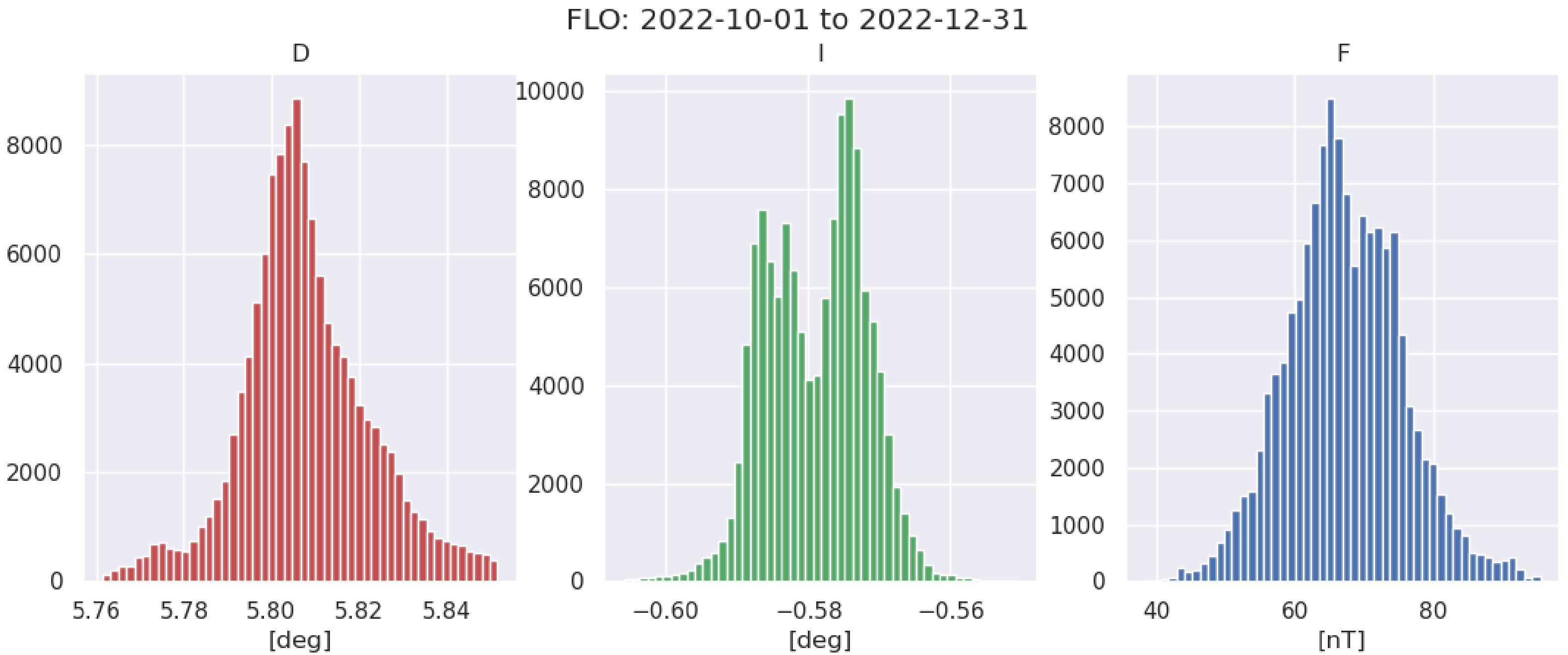
FLO: 2022-10-01 to 2022-12-31



FLO: ESK/LER differences

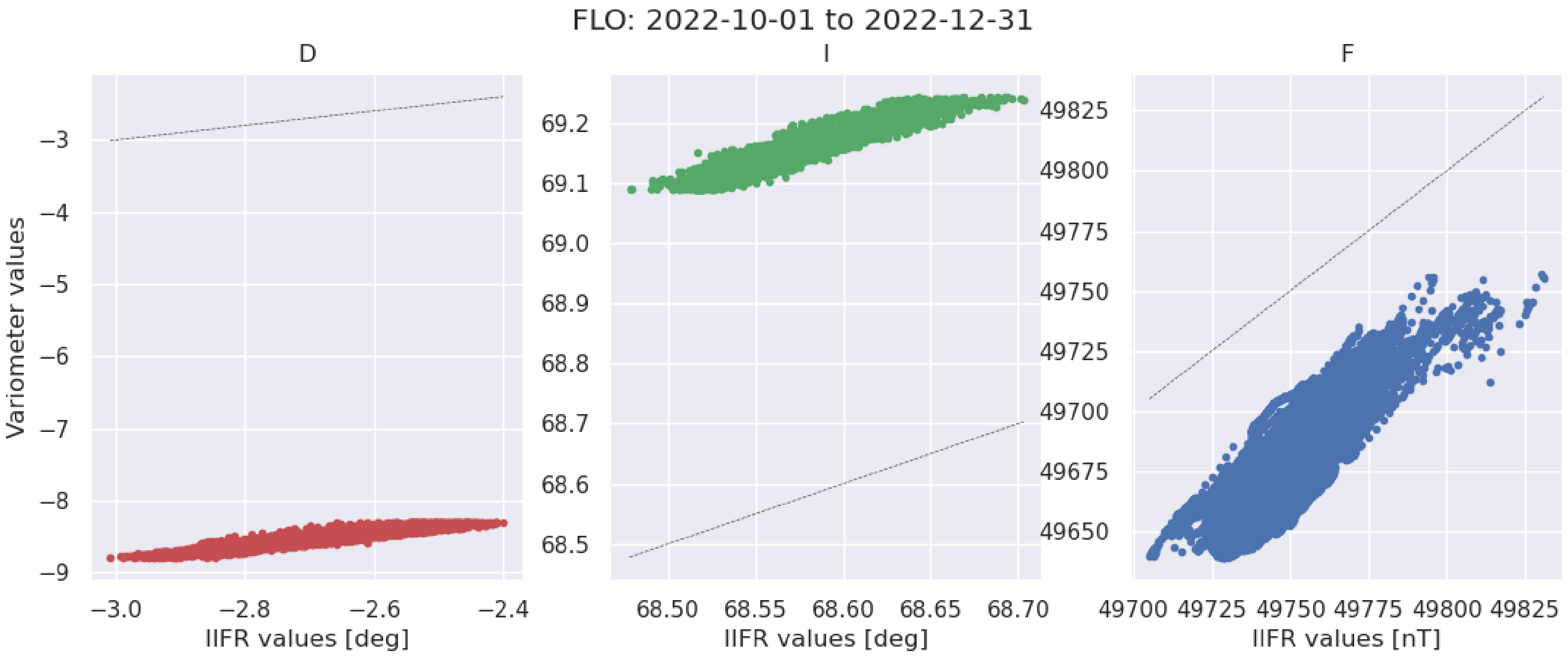


FLO: ESK/LER differences* histogram



* Values >3.5σ have been removed

FLO:ESK/LER scatter plot of IIFR vs measurements

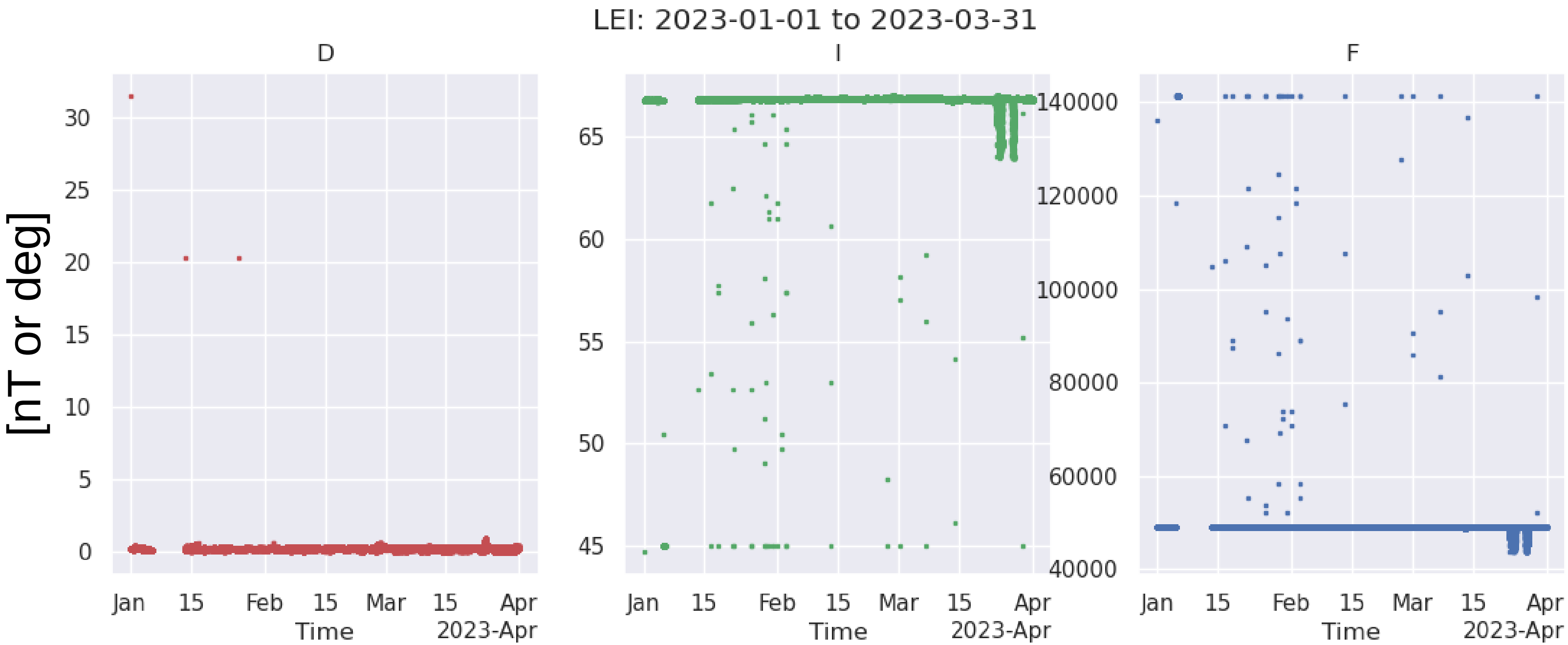


FLO Statistics

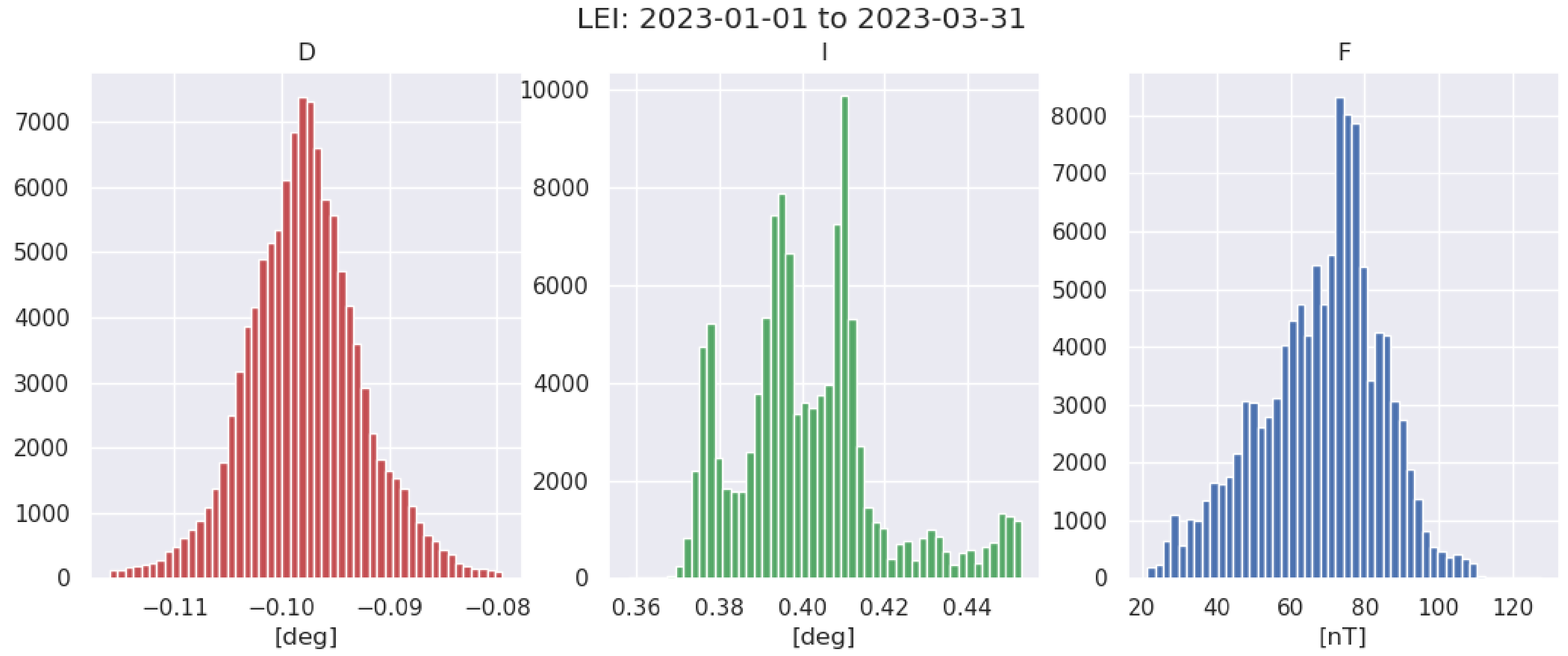
	D (°)	I (°)	F (nT)
# data	131790	131790	131790
mean	5.809	-0.579	67.2
std	0.018	0.007	8.4
min	5.643	-0.633	36.9
max	5.975	-0.535	102.0

Conclusion: Variation is very well captured. Absolute level is very poor

LEI: 2023-01-01 to 2023-03-31



LEI:ESK/HAD differences* histogram



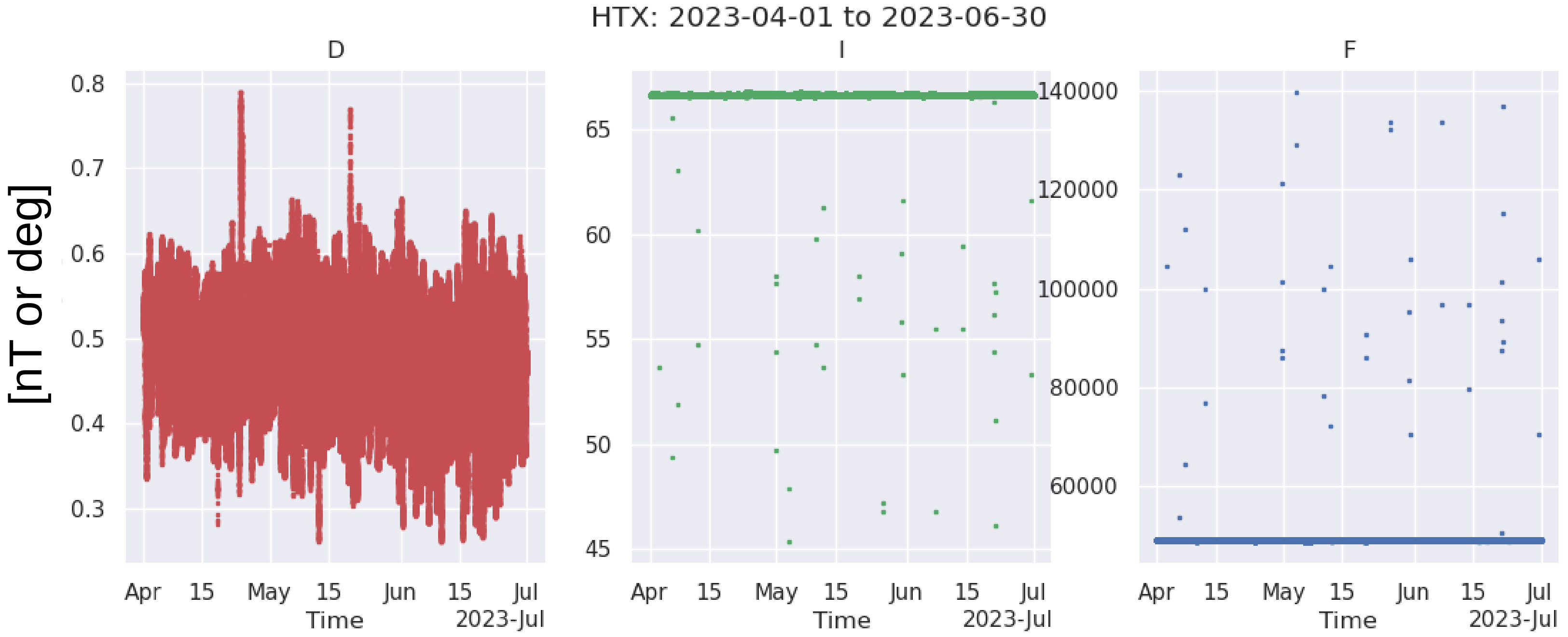
* Values >3.5σ have been removed

LEI Statistics

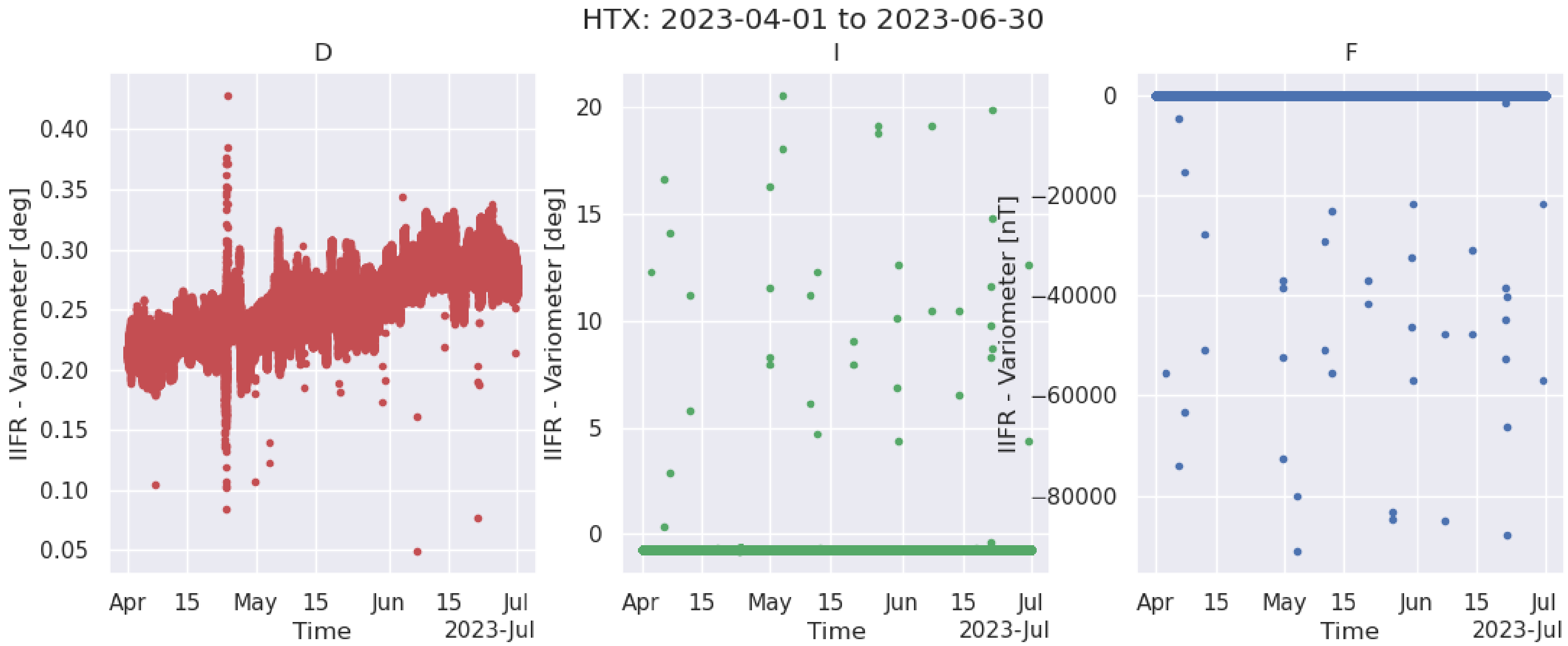
	D (°)	I (°)	F (nT)	
# data	118354	118354	118354	
mean	-0.091	0.574	-515.0	✗
std	0.131	1.797	7558.4	✗
min	-31.460	0.358	-92238.4	
max	0.507	22.532	5264.1	

Conclusion: Several periods of poor quality contribute large errors but other periods are OK. Absolute level is not within ISWSA uncertainty.

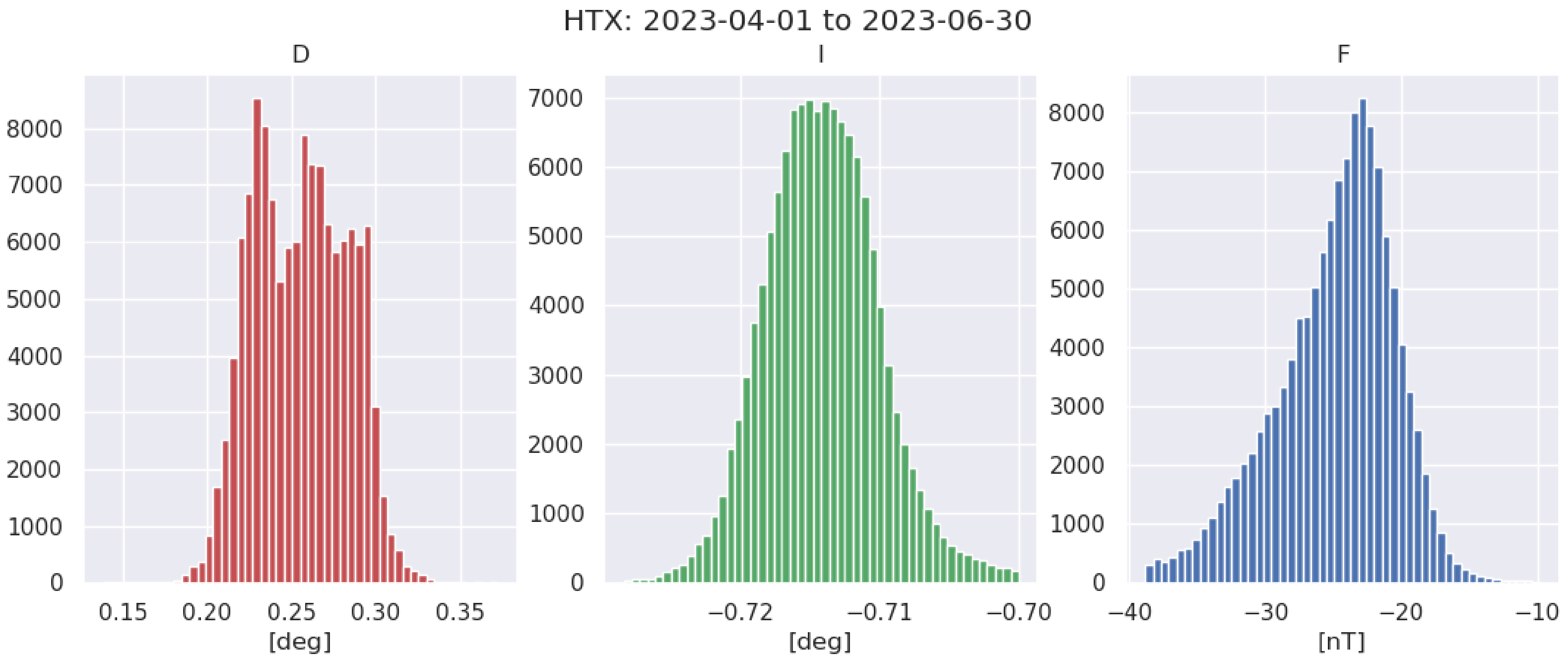
HTX: 2023-04-01 to 2023-06-30



HTX:HAD differences

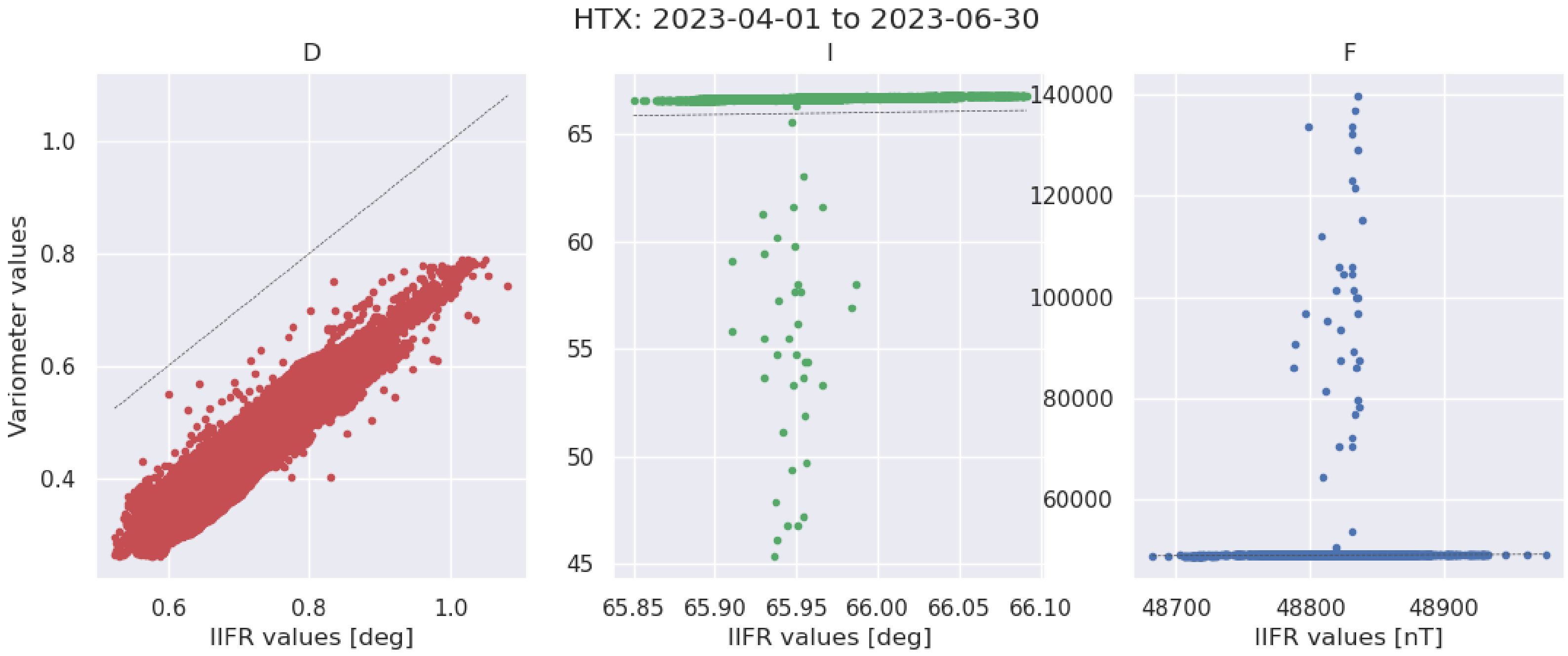


HTX:HAD differences* histogram



* Values >3.5σ have been removed

HTX:HAD scatter plot of IIFR vs measurements



HTX Statistics

	D (°)	I (°)	F (nT)	
# data	129415	129415	129415	
mean	0.255	-0.711	-39.4	✗
std	0.028	0.215	919.8	✗
min	0.049	-0.775	-91046.1	
max	0.429	20.577	43.7	

Conclusion: Several periods of poor quality contribute large (Z) errors.
Not as well levelled as expected.

Considerations

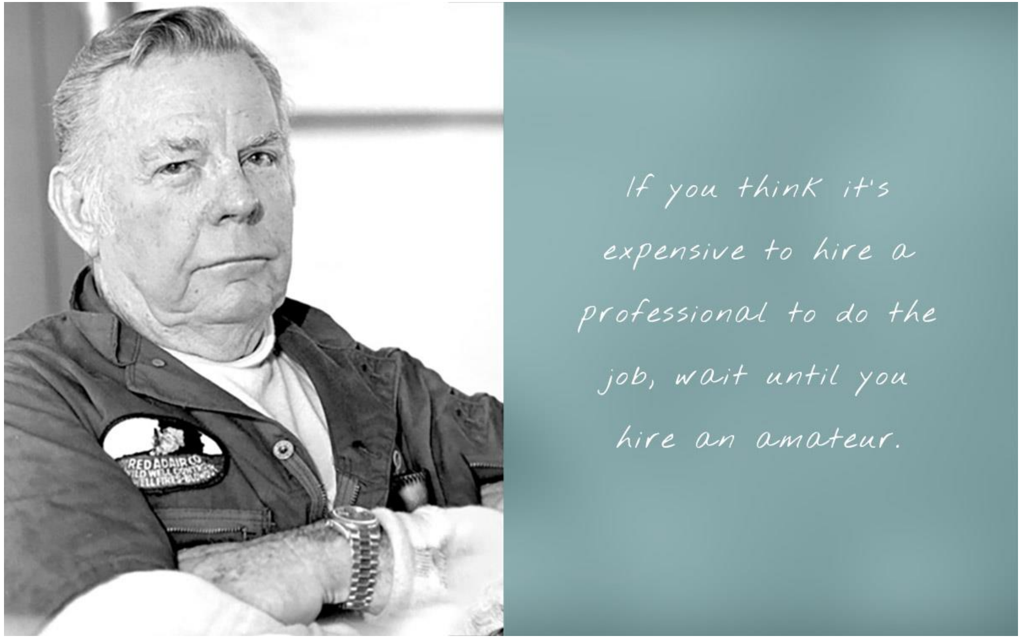
- IFR2 using observatory data produces correct orientation and variation well within standard uncertainties (<< [0.1°, 0.05°, 50 nT])
- Variometers provide good variation w.r.t. IFR2 (standard dev is usually small) but poor absolute values
- Variometers are prone to spikes, offsets and unknown orientation even with good care in quiet locations
- There are periods of good data but must be monitored continuously

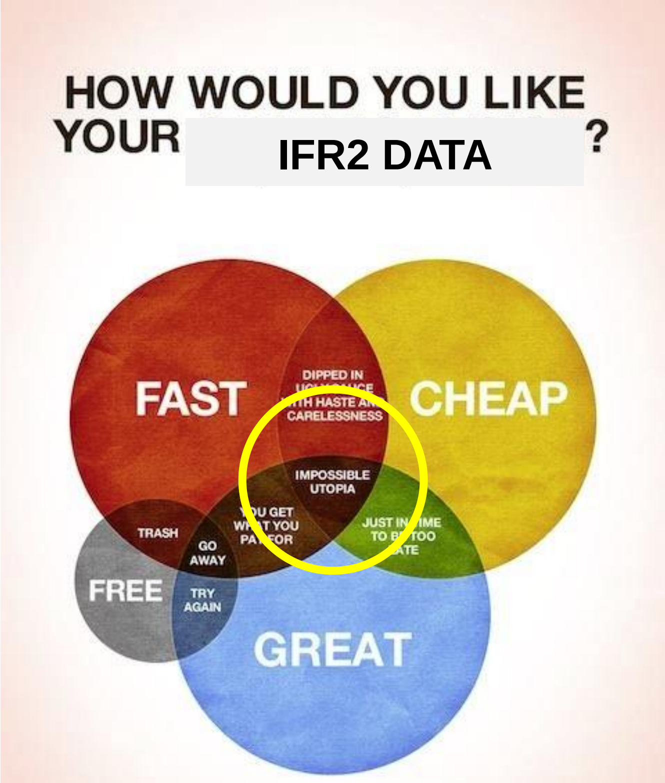
Summary

- In theory, correctly orientating a variometer with a spot D/I/F measurement could provide IFR2 but with larger uncertainties.
- In general, rigside variometers cannot provide the level of accuracy needed for IFR2 ***without a lot of care and attention***
- If *available*, easier/more confidence to use observatories for IFR2
  - Other benefits are continuous QC, instrument/comms redundancy, access to expert knowledge, low noise environments etc …

Conclusions

Like most things in life – no free lunch!





Questions?

QC, redundancy & backup