British Geological Survey
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Gateway to the Earth

IAGA XVIIIth IAGA Workshop Summer School

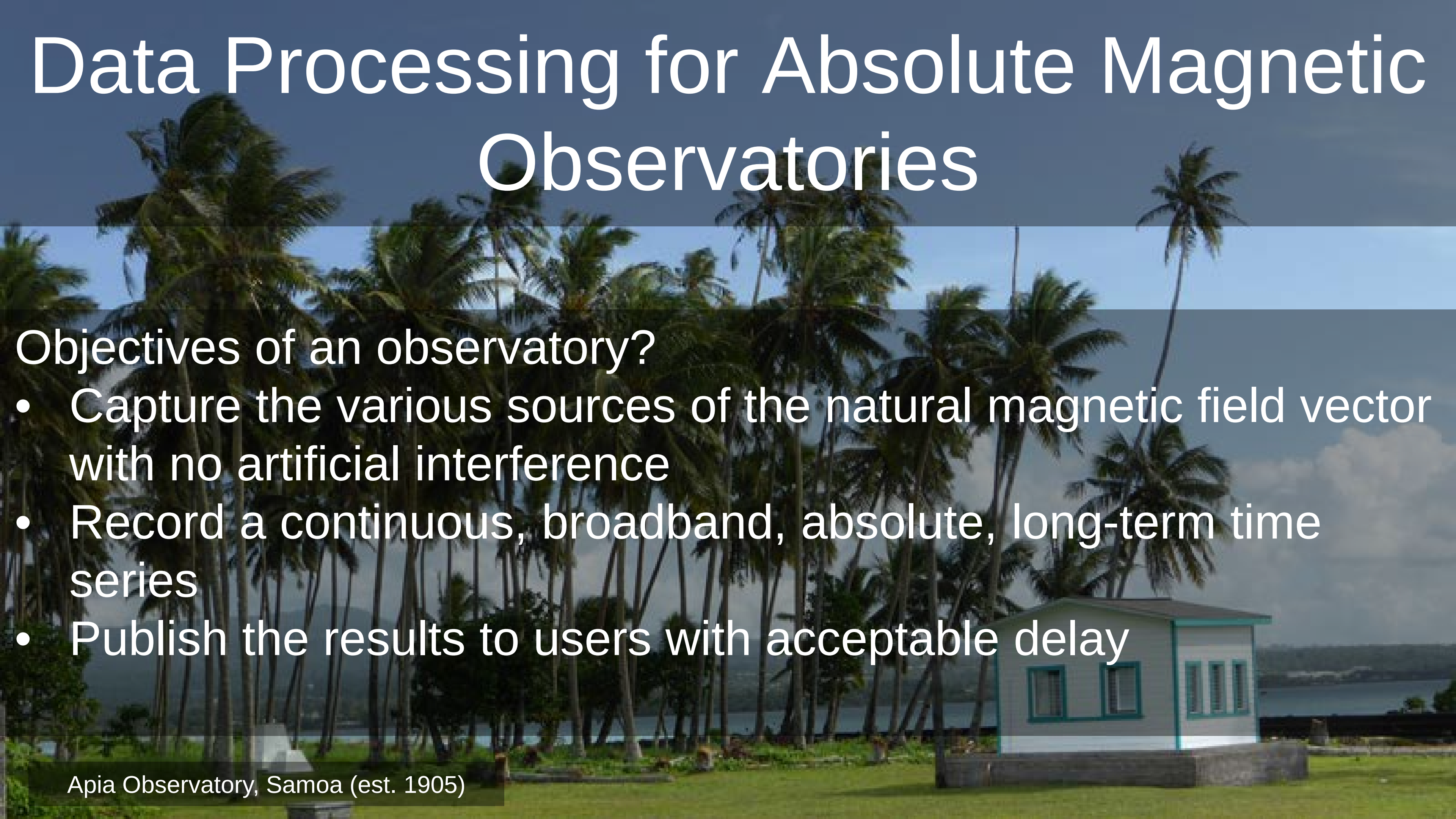
Data Processing

Chris Turbitt, British Geological Survey

Data Processing for Absolute Magnetic Observatories

Objectives of an observatory?

- Capture the various sources of the natural magnetic field vector with no artificial interference
- Record a continuous, broadband, absolute, long-term time series
- Publish the results to users with acceptable delay

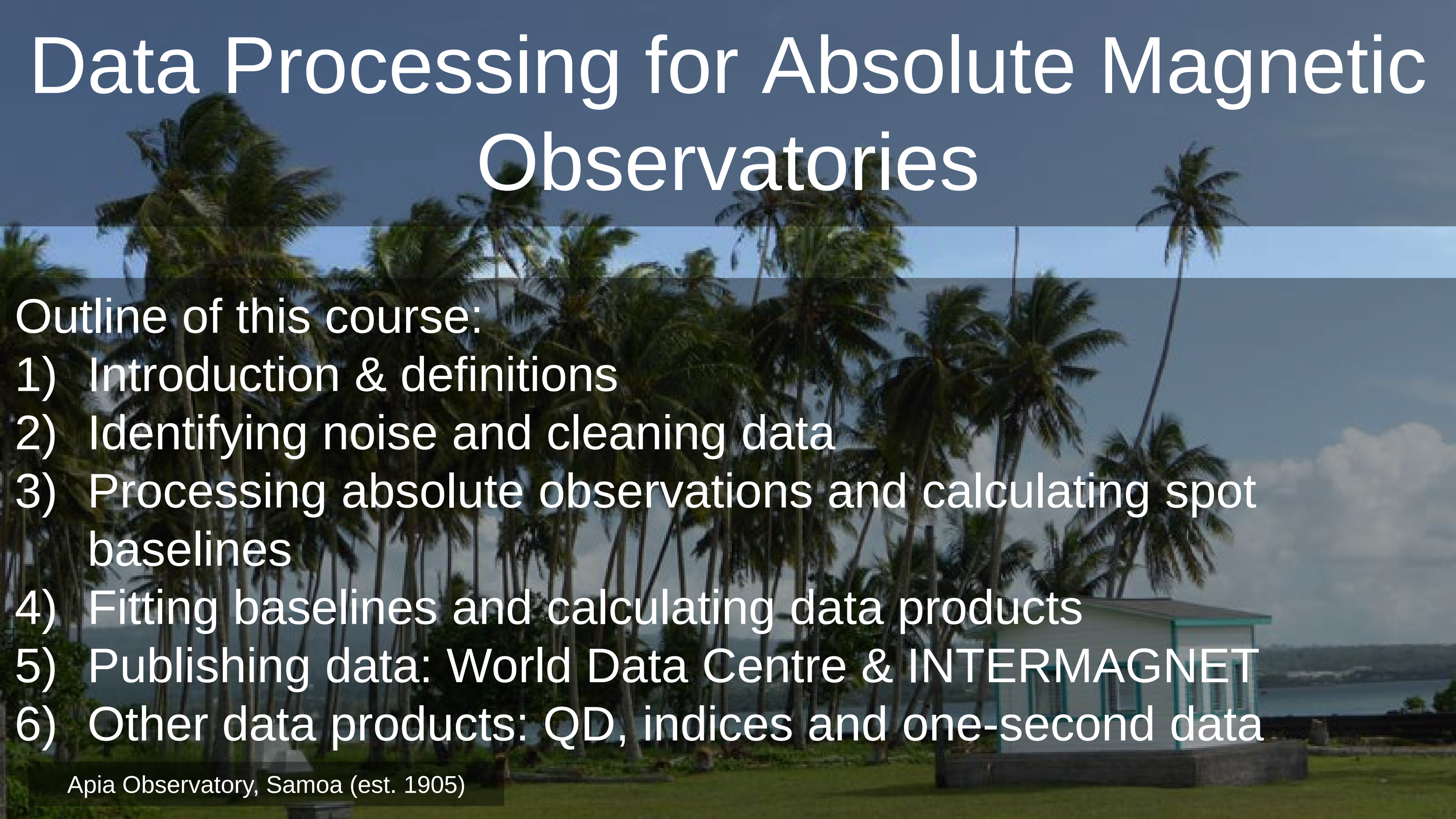


Apia Observatory, Samoa (est. 1905)

Data Processing for Absolute Magnetic Observatories

Outline of this course:

1) Introduction & definitions
2) Identifying noise and cleaning data
3) Processing absolute observations and calculating spot baselines
4) Fitting baselines and calculating data products
5) Publishing data: World Data Centre & INTERMAGNET
6) Other data products: QD, indices and one-second data



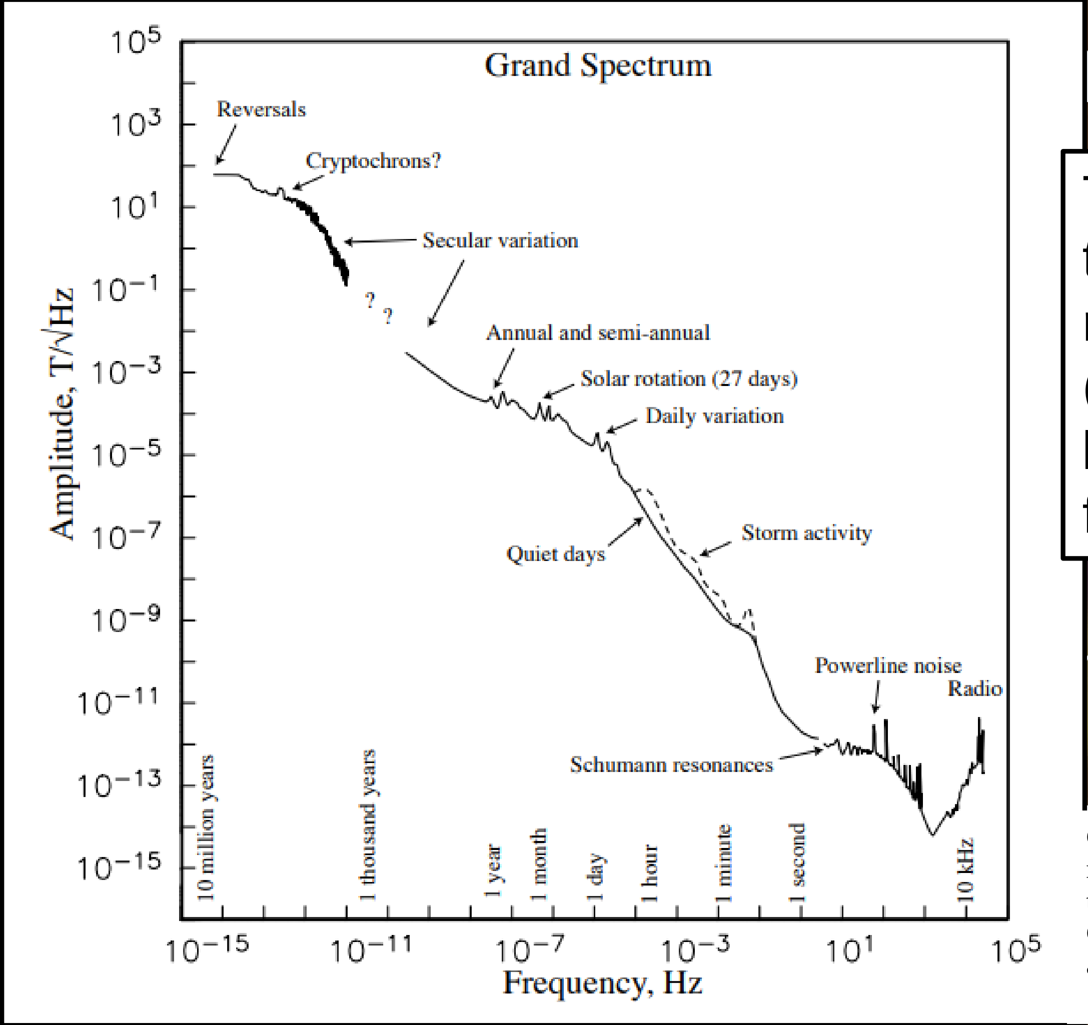
Apia Observatory, Samoa (est. 1905)

Why so challenging?

Natural field sources:

- Core field 20-60μT, slowly varying months to millennia
- Crustal field ~5% of core field, ~static
- External field (ionosphere, magnetosphere) 1-10%, varies <seconds to >decades
- Other fields: induced fields, ocean currents, etc.

ging?



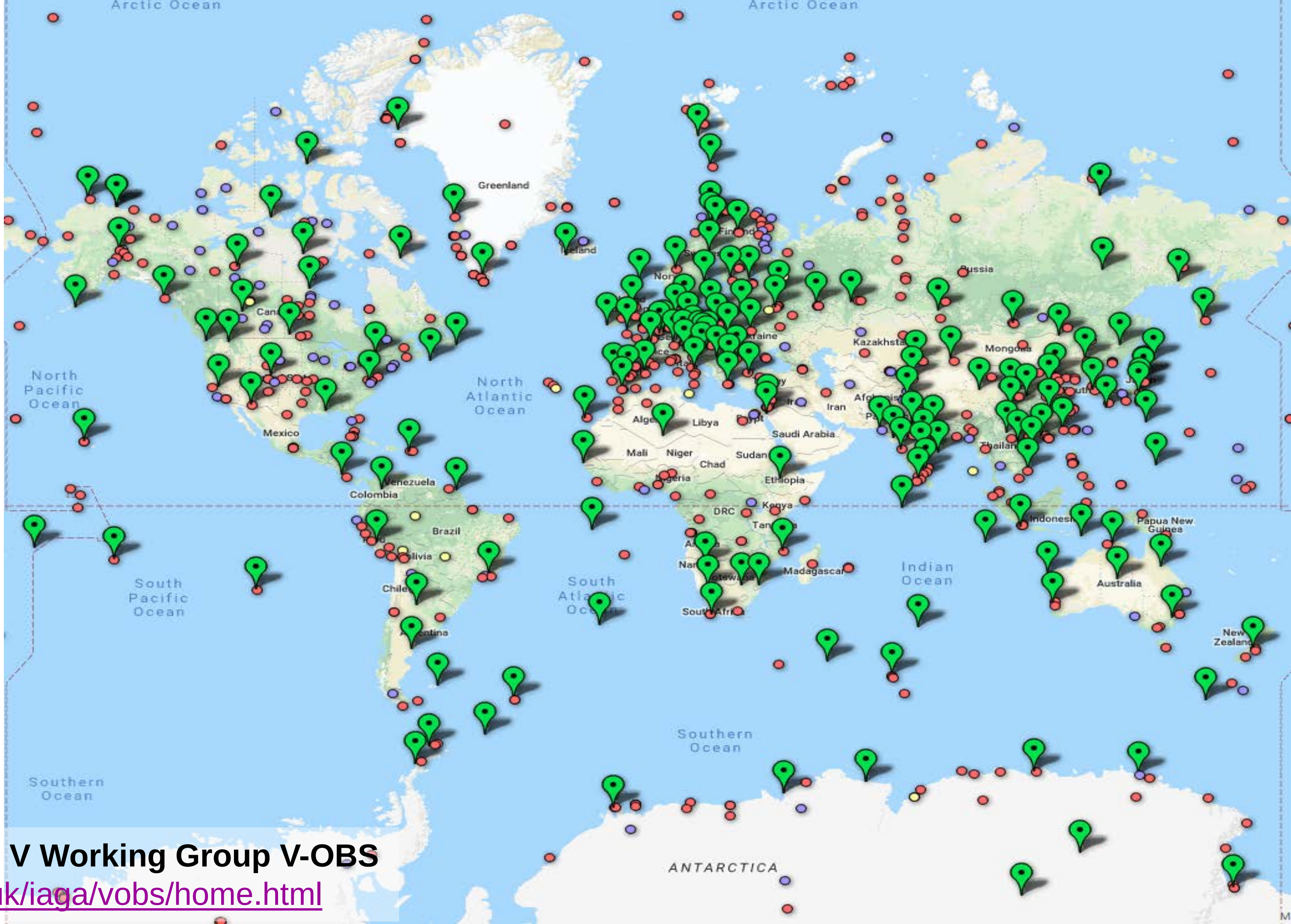
To capture a broad band of the natural magnetic signal requires a stable instrument (or set of instruments) with large dynamic range operated for a long period of time

Na

-
-
- here) 1-10%, varies
-

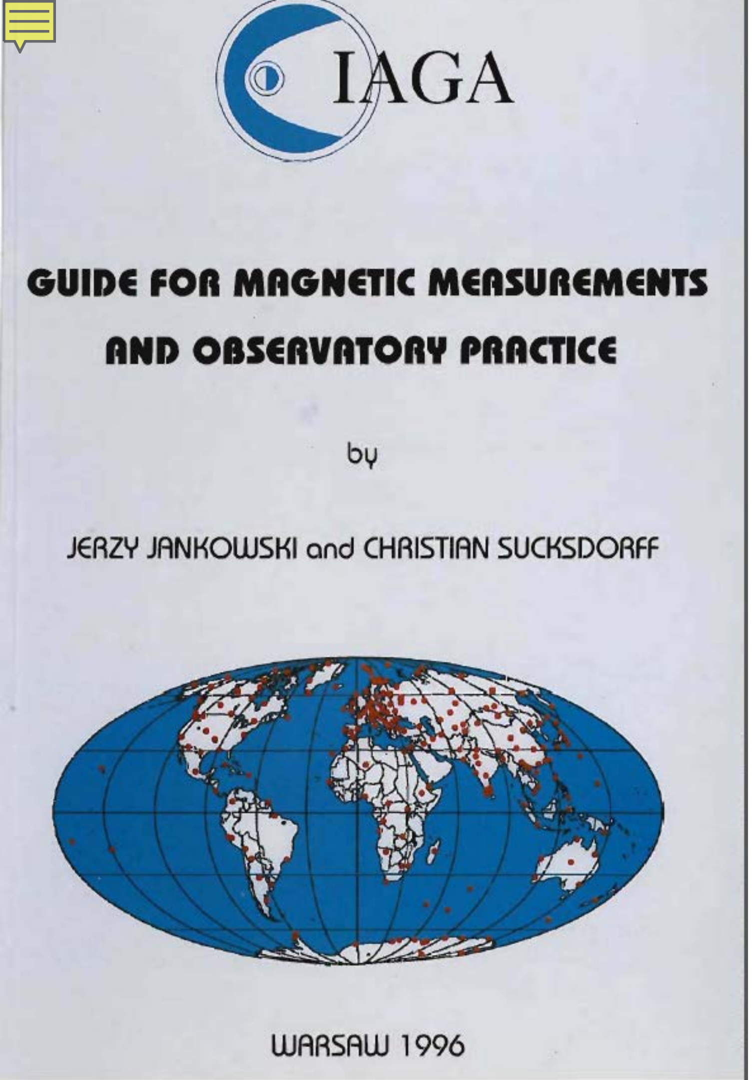
Constable, C.G., & S.C. Constable, 2004. Satellite magnetic field measurements: applications in studying the deep earth. In "The State of the Planet: Frontiers and Challenges in Geophysics", ed. R.S.J. Sparks and C.J. Hawkesworth, American Geophysical Union. DOI 10.1029/150GM13, pp. 147–160.

Global Observatory Network



Source: **IAGA Division V Working Group V-OBS**

http://www.bgs.ac.uk/iaga/vobs/home.html



Resources

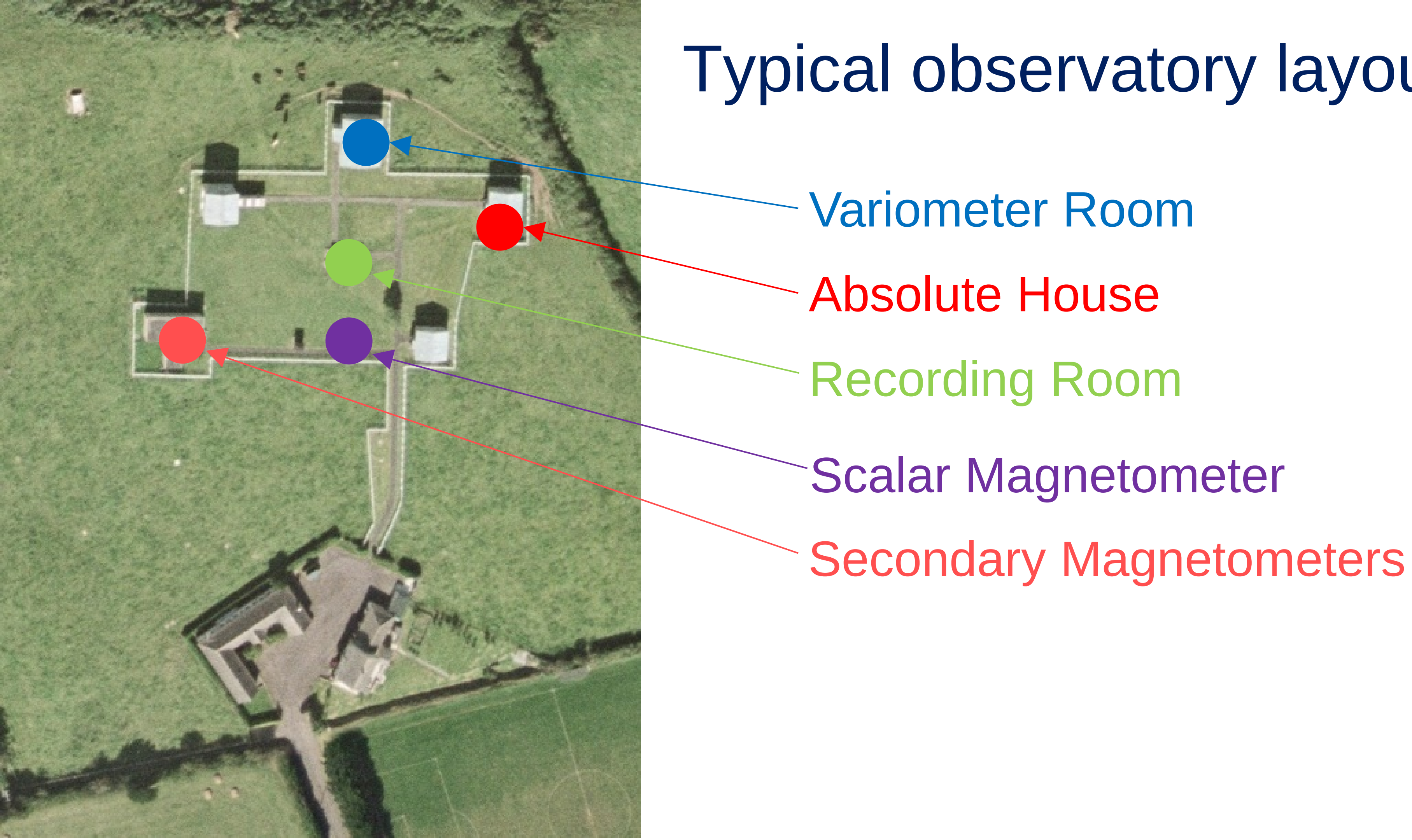
IAGA Observatory Guide

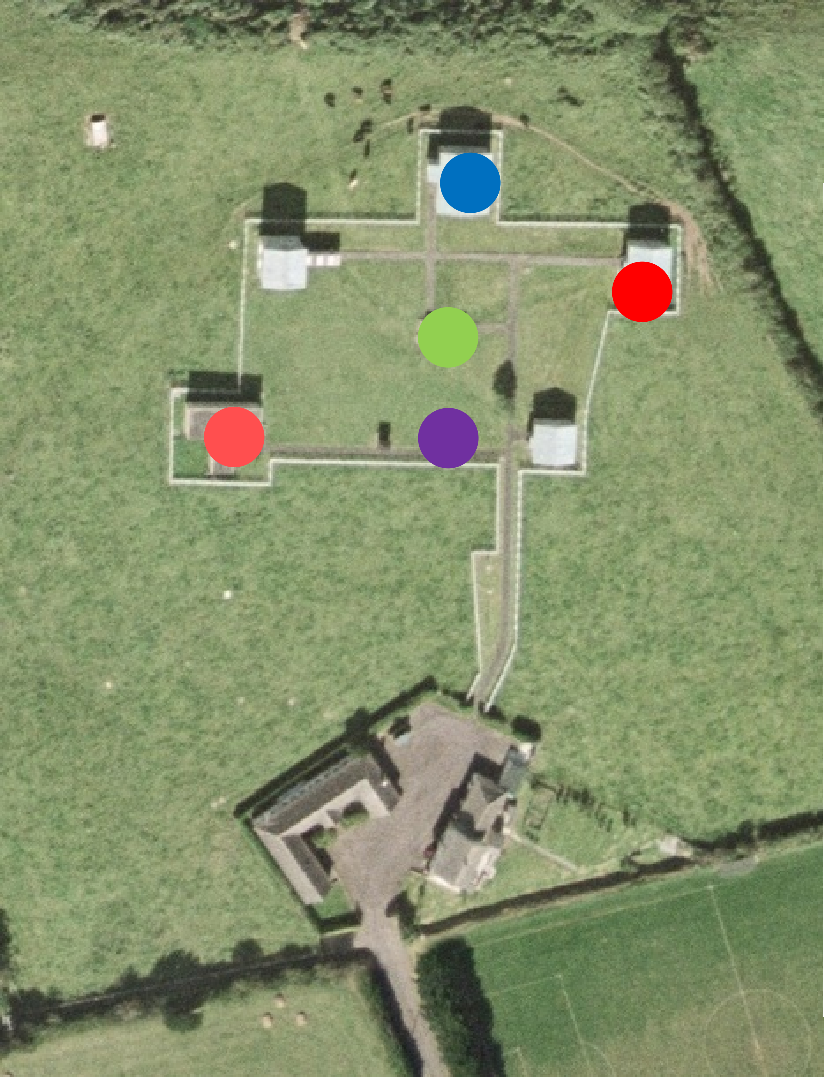
http://www.iaga-aiga.org/data/uploads/pdf/guides/iaga-guide-observatories.pdf

INTERMAGNET Technical Manual:

http://intermagnet.org/publication-software/technicalsoft-eng.php

Typical observatory layout





Typical observatory layout

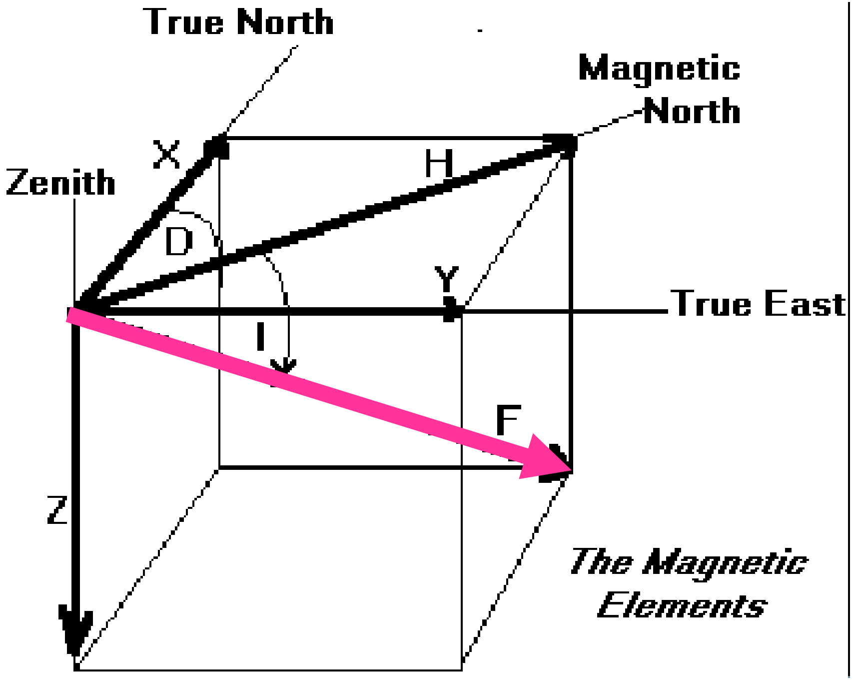
Most important location in any observatory is the absolute pillar in the absolute house. All recorded data is ultimately corrected to this position, providing the long, continuous time-series. Hence this position must not change and must be kept magnetically clean.

Vector variometer data, which are typically not absolute, are corrected to near absolute values at the pillar by means of baselines. These baselines can change over time and must be routinely measured (absolute observations) and modelled.

Scalar magnetometer data are corrected to the absolute pillar by means of scalar site differences, measured by periodically running another scalar magnetometer on the absolute pillar.

Secondary magnetometers can provide additional quality control measures and can be used to fill gaps in the primary systems

Geomagnetic Field Components



Code	Description
X	Geographic north
Y	Geographic east
Z	Vertical intensity
H	Horizontal intensity
D	Declination or variation
I	Inclination
F	Total field intensity.

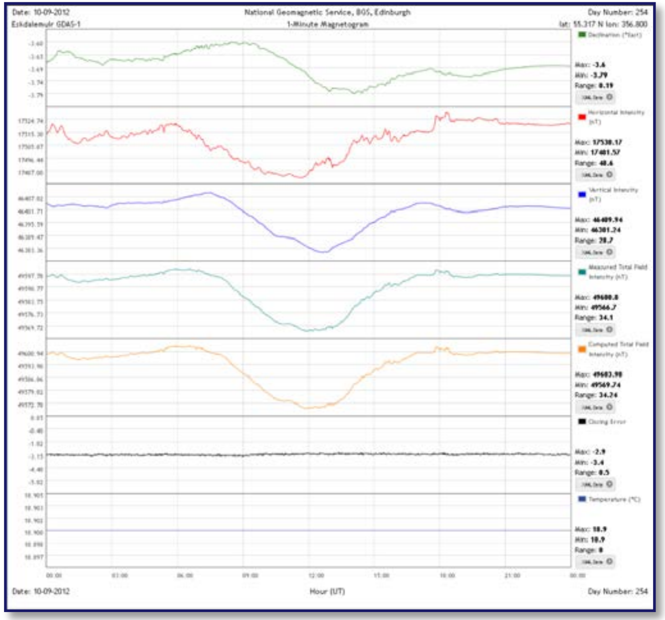
Geomagnetic Field Components
INTERMAGNET Technical Manual

Code	Description
X	North Component. The strength of the magnetic field vector in the geographic north direction (southerly values are –ve).
Y	East component. The strength of the magnetic field vector in the geographic east direction (westerly values are –ve).
Z	Vertical intensity. The strength of the magnetic field vector in the vertical direction. Z is upward positive downwards and hence negative in the southern hemisphere.
H	Horizontal intensity. The strength of the magnetic field vector in the horizontal plane along the magnetic meridian.
D	Declination or variation. The angle between the magnetic vector and true north positive east.
I	Inclination. The angle between the magnetic vector and the horizontal plane, in degrees of arc, positive above the horizontal.
F	Total field intensity. The geomagnetic field strength, calculated from and consistent with XYZ or HDZ field elements.
S	Scalar field intensity. The geomagnetic field strength, measured using an instrument that is independent from that used to measure the vector field values.
G	Delta-F. Delta-F is defined as F(vector)–S(scalar) in nT. When calculating values for the G element, if F(vector) is missing, G is set to –S (scalar)
E	A field strength in the horizontal plane perpendicular to ‘H’. ‘E’ is only valid for data that is not baseline corrected.
V	The field strength along the direction of the inclination.
A	NW component.
B	EW component, 'B' is perpendicular to 'A'.

Data Types
INTERMAGNET Technical Manual

Data type	Formats where it can be used	What it means
Reported	IMFV1.23 (as a metadata field) and IMFV2.83 (implied – data in this format can only be 'Reported').	Preliminary data from an observatory that has not had any baseline corrections applied. It may contain spikes and may have missing values.
Variation	IAGA-2002 (as a metadata field)	The data type is not defined in the format definition .It is assumed to contain data to the same definition as the 'Reported' data type.
Adjusted	IMFV1.23 (as a metadata field)	Adjusted data may have modifications made to raw data to apply baselines, remove spikes or fill gaps.
Provisional	IAGA-2002 (as a metadata field)	The data type is not defined in the format definition. It is assumed to contain data to the same definition as the 'Adjusted' data type.
Quasi-definitive	IMFV1.23, IAGA-2002 and IAFV2.11 (as a metadata field)	Quasi-definitive data are defined as data that have been corrected using provisional baselines. Produced soon after data acquisition, their accuracy is intended to be very close to that of an observatory's definitive data product. 98% of the differences between quasi-definitive and definitive data monthly mean values should be less than 5nT in (X, Y, Z) orientation.
Definitive	IMFV1.23, IAGA-2002 and IAFV2.11 (as a metadata field) and IAF version prior to V2.11 (implied - data in this format can only be 'Definitive').	Observatory data which have been corrected for baseline variations, have had spikes removed and gaps filled where possible. No further change is expected and the quality of the data is such that they would be used for inclusion in observatory year books and for input to the World Data Centers and the annual INTERMAGNET CD/DVD.

Data Processing Tasks

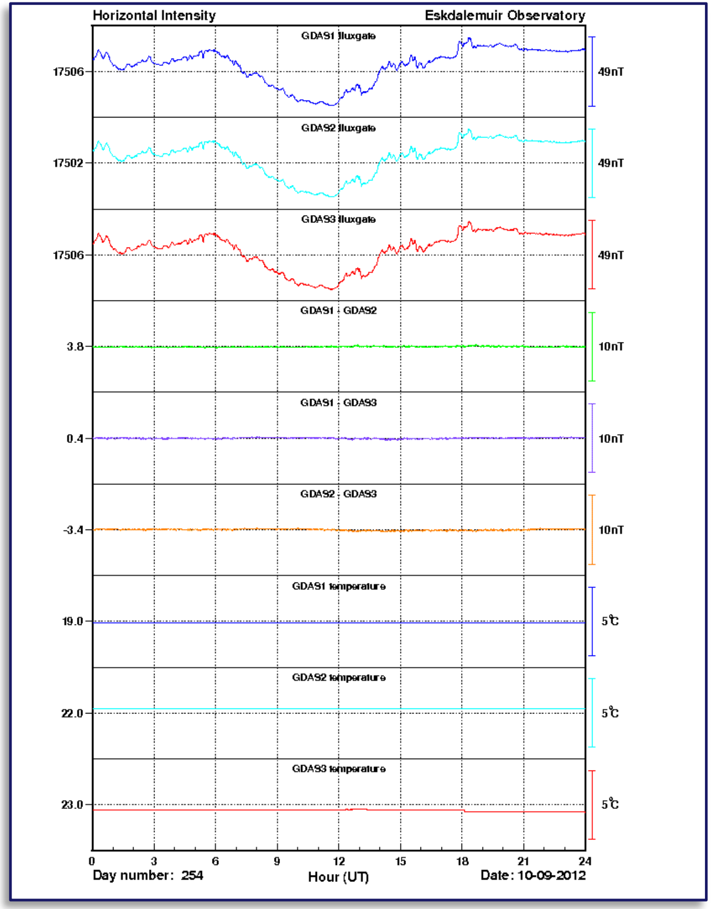


Daily

Daily observatory tasks:

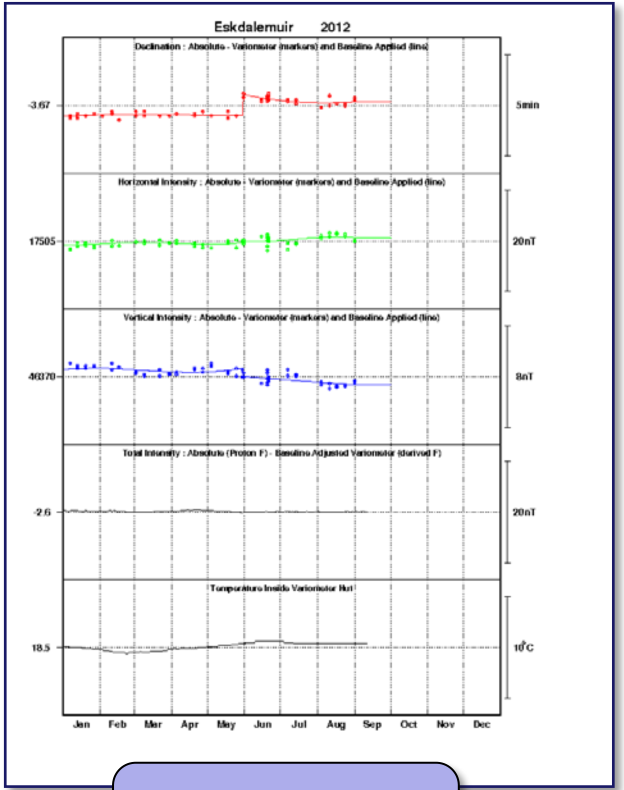
- Record well-timed, correctly scaled variometer data
- Filter base data to one-minute (/one-second) using suitable filter
- Plot and inspect magnetograms
- Compare instruments and compare with nearby observatories
- Cross-correlation can be used to detect timing inconsistencies
- Correct for spikes and estimate steps
- Record observatory changes and events in the observatory diary
- Transmit 'real-time', 'reported' data within 72 hours with approximate baselines
- Optionally transmit observatory indices

Data Processing Tasks



- Instrument comparisons are a very useful quality control tool.
- They are effectively a very sensitive gradiometer to detect instrument problems or changes in the measuring environment.
- Three or more systems help to identify where the source of the problem is

Data Processing Tasks



Weekly

Weekly observatory tasks:

- Absolute observations
- Scalar site difference measurement
- Calculate spot baselines
- Plot interim baselines
- Evaluate and adjust for steps
- Identify excessive drifts or steps
- Transmit ‘adjusted’ data with interim baselines within 7 days

Scalar Site Difference Measurements

This is the total field correction between the continuously recording scalar magnetometer and the absolute pillar

The scalar site difference is used to correct recorded scalar data to the absolute pillar to process absolute observations and to assess the quality of the variometer data

Site differences can change over time, particularly when there is a change to the continuously recording scalar magnetometer

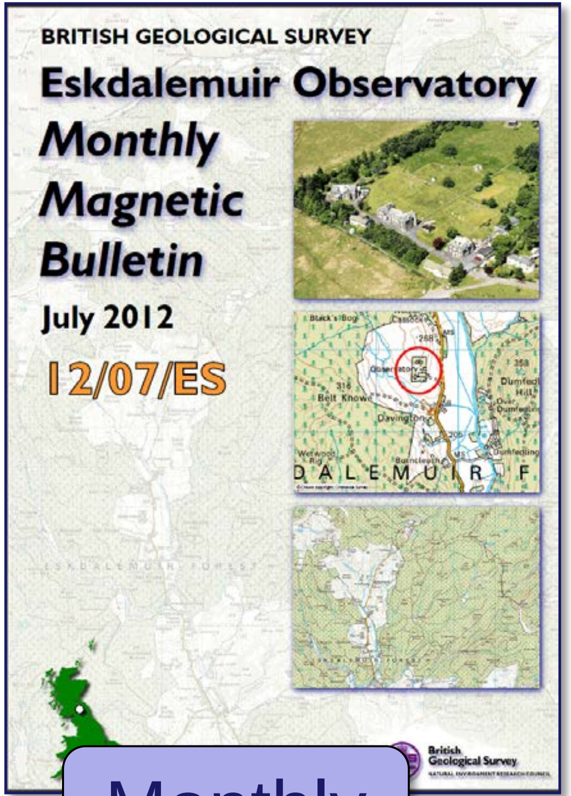
This measurement is often neglected and frequently leads to gross errors in definitive data processing

Very easily measured by running a second scalar magnetometer for a few minutes on the absolute pillar with the absolute instrument removed (>5m away)

This measurement is still important at observatories without a continuously recording scalar magnetometer.

Measurements can be made using a single scalar magnetometer by alternating its between its normal position and the absolute pillar

Data Processing Tasks

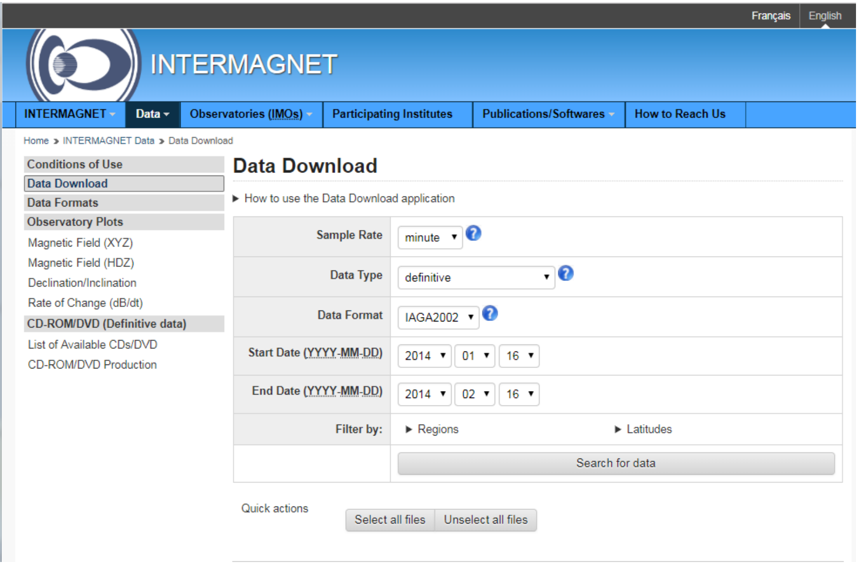


Monthly

Monthly observatory tasks:

- Re-evaluate baselines and variometer data
- Consider producing a monthly bulletin: publishing magnetograms, baselines and a log of observatory changes
- Optionally publish quasi-definitive data (<3 months)

Data Processing Tasks



Annual observatory tasks:

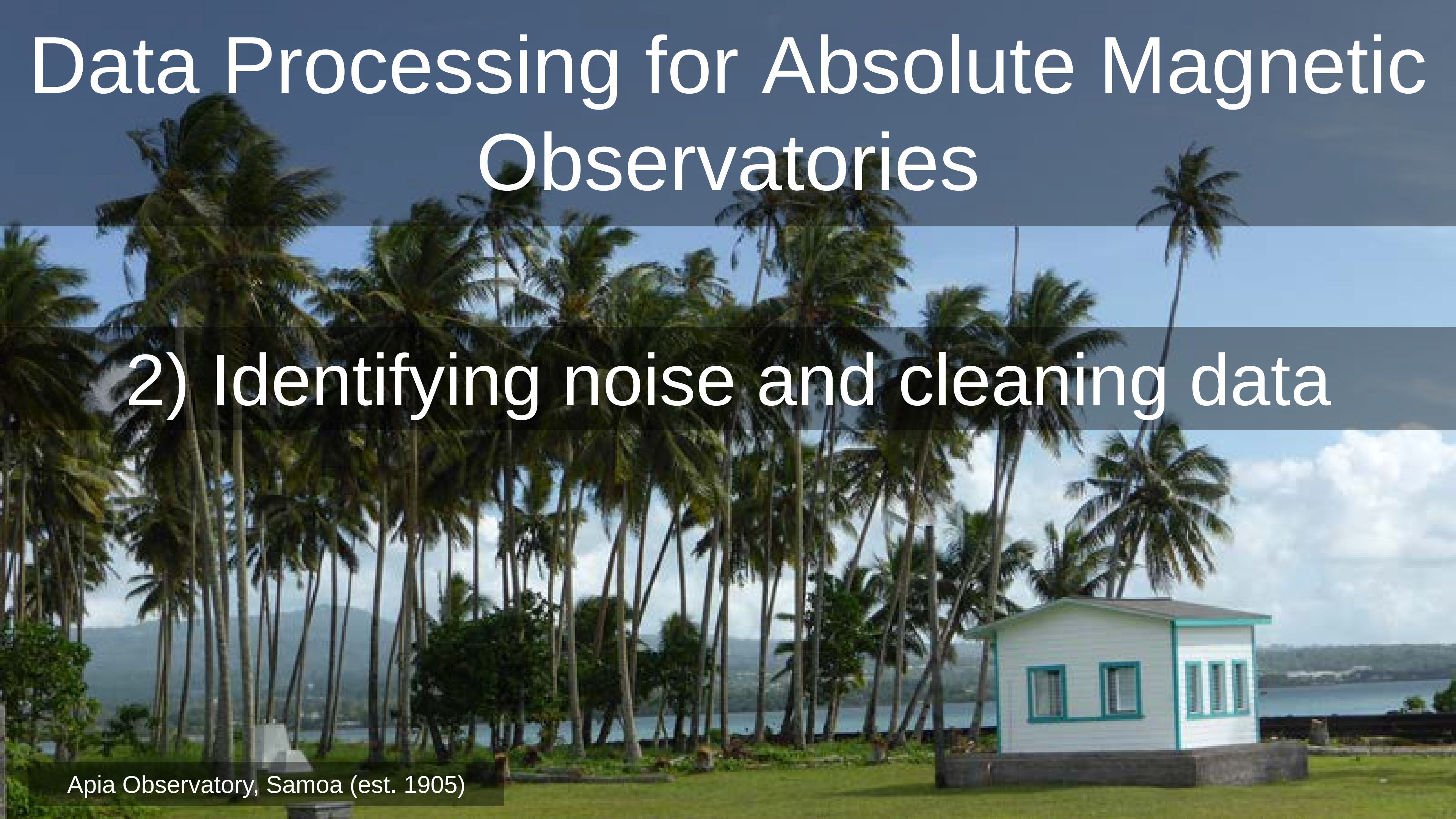
- Finalise baselines and variometer data
- Calculate data products such as definitive data with hourly, daily, monthly and annual means
- Produce and publish observatory yearbook
- Publish data & metadata to World Data Centre or INTERMAGNET*

Yearly

*definitive data published via INTERMAGNET are automatically sent to WDC

Data Processing for Absolute Magnetic Observatories

2) Identifying noise and cleaning data



Apia Observatory, Samoa (est. 1905)

Observatory Noise Sources
(Jankowski & Sucksdorff)

Distances of selected objects producing ~1nT magnetic field

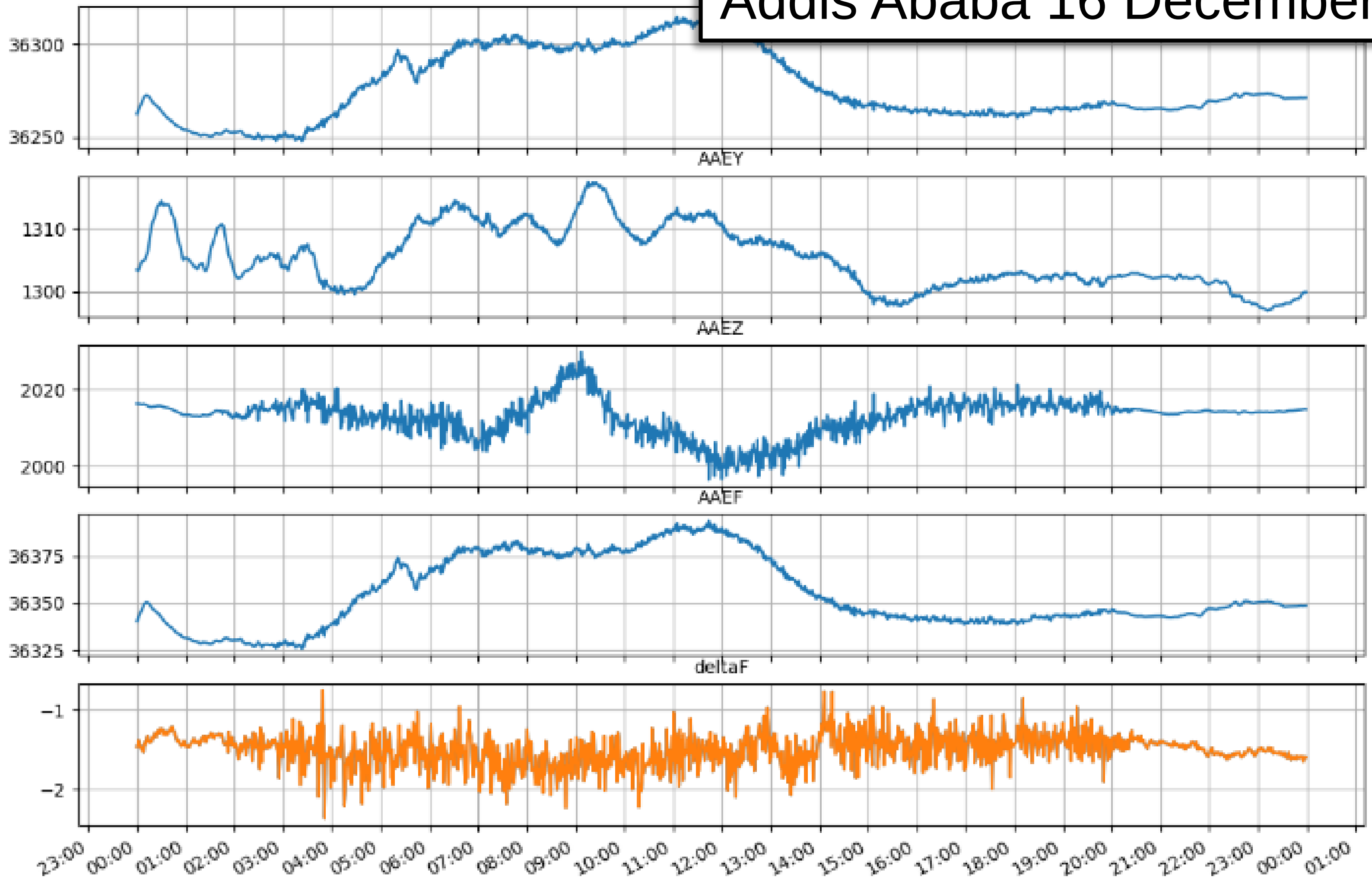
- 1m watch, pen, belt buckle
- 2m knife, screwdriver
- 5m spade
- 7m bicycle
- 40m car
- 80m bus
- 1km diesel railroad, 10km AC electric railroad
- 10s km DC electric railroad

Recommendation:

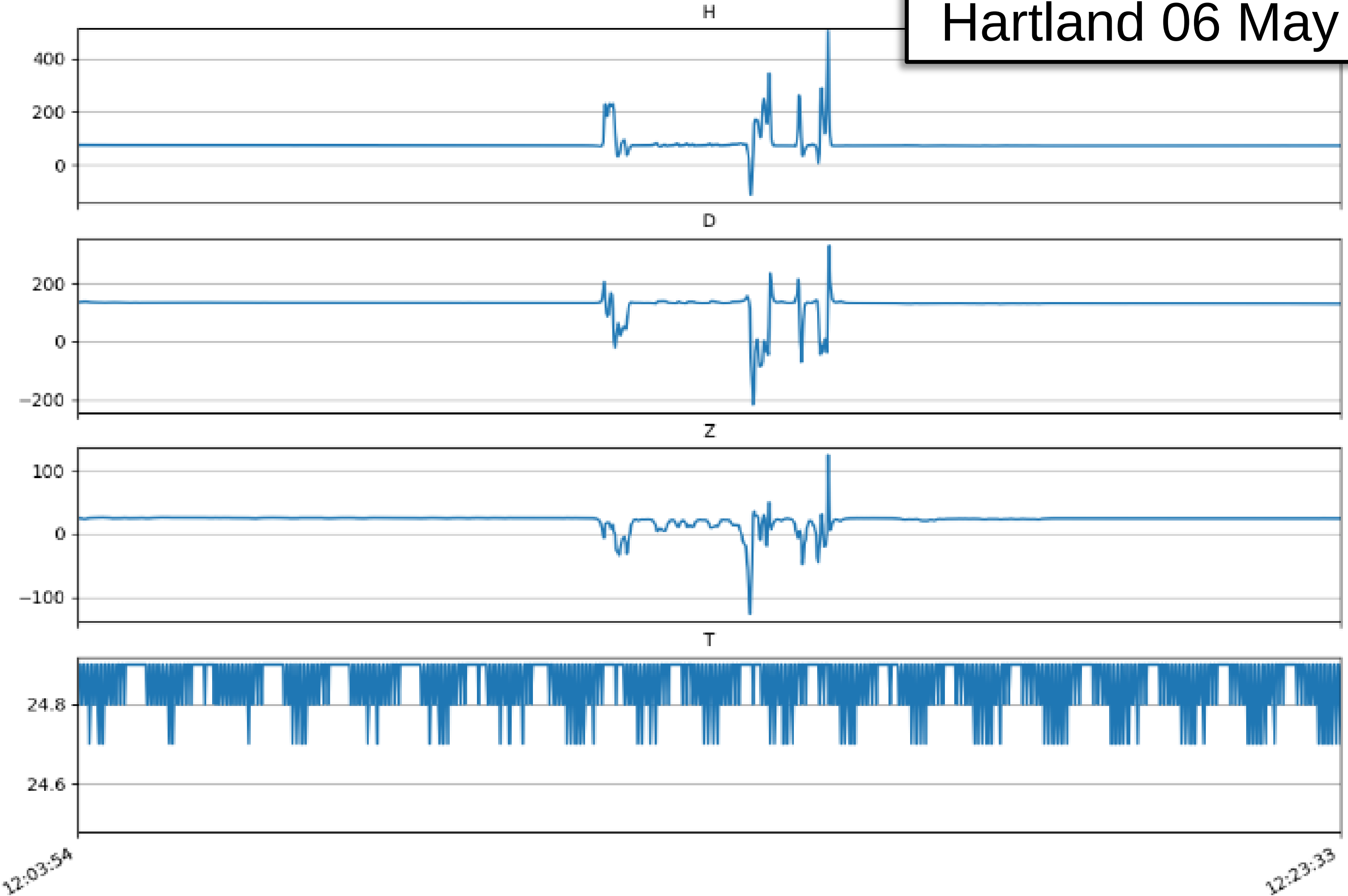
- <1nT/m gradient
- 300m perimeter around absolute house

Further information on noise sources, detection and repair: Noise in raw data from magnetic observatories, Sergey Y. Khomutov, Oksana V. Mandrikova, Ekaterina A. Budilova, Kusumita Arora, and Lingala Manjula, Geosci. Instrum. Method. Data Syst., 6, 329-343, https://doi.org/10.5194/gi-6-329-2017, 2017

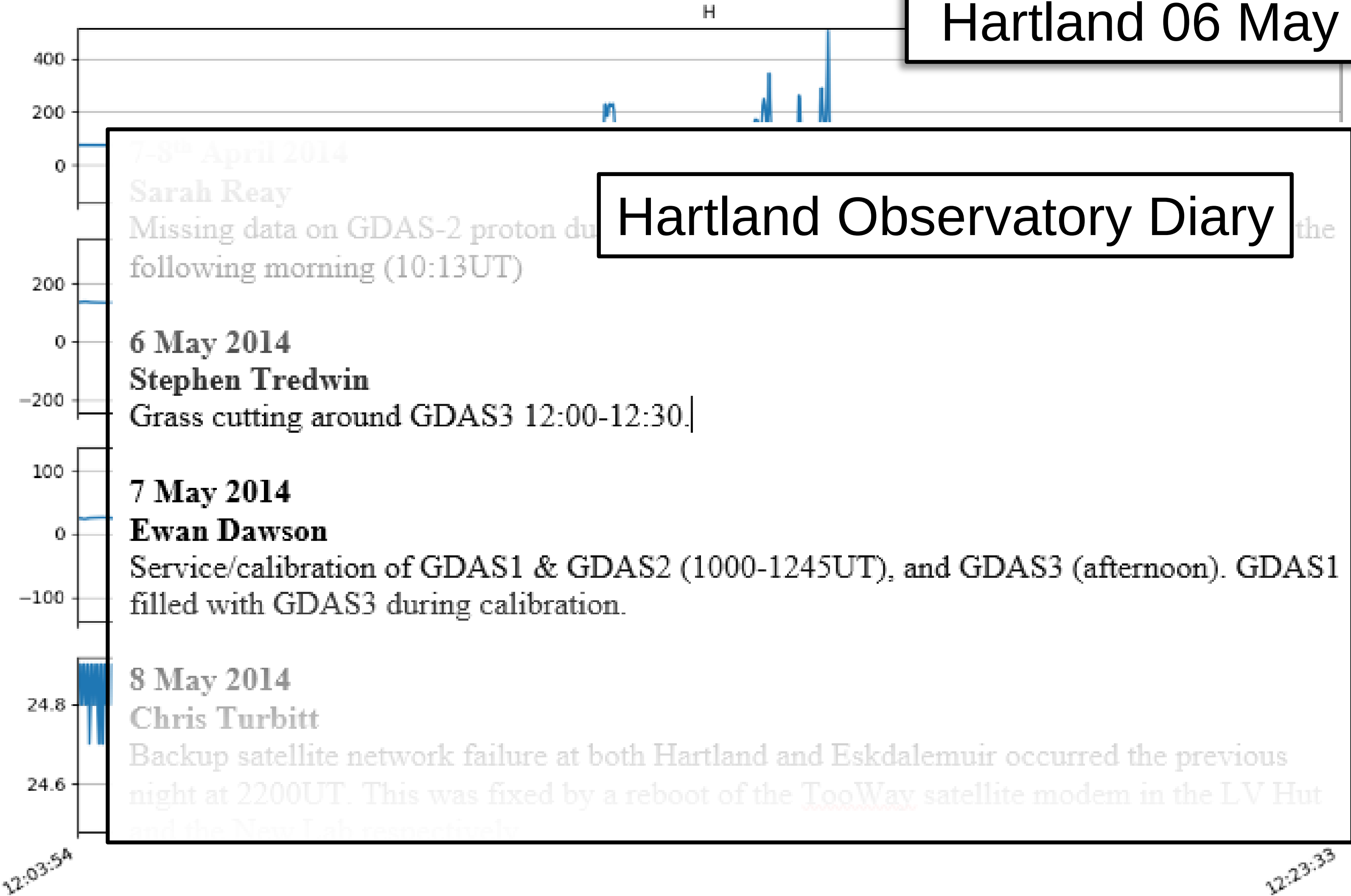
Addis Ababa 16 December 2015



Hartland 06 May 2014



Hartland 06 May 2014



Hartland Observatory Diary

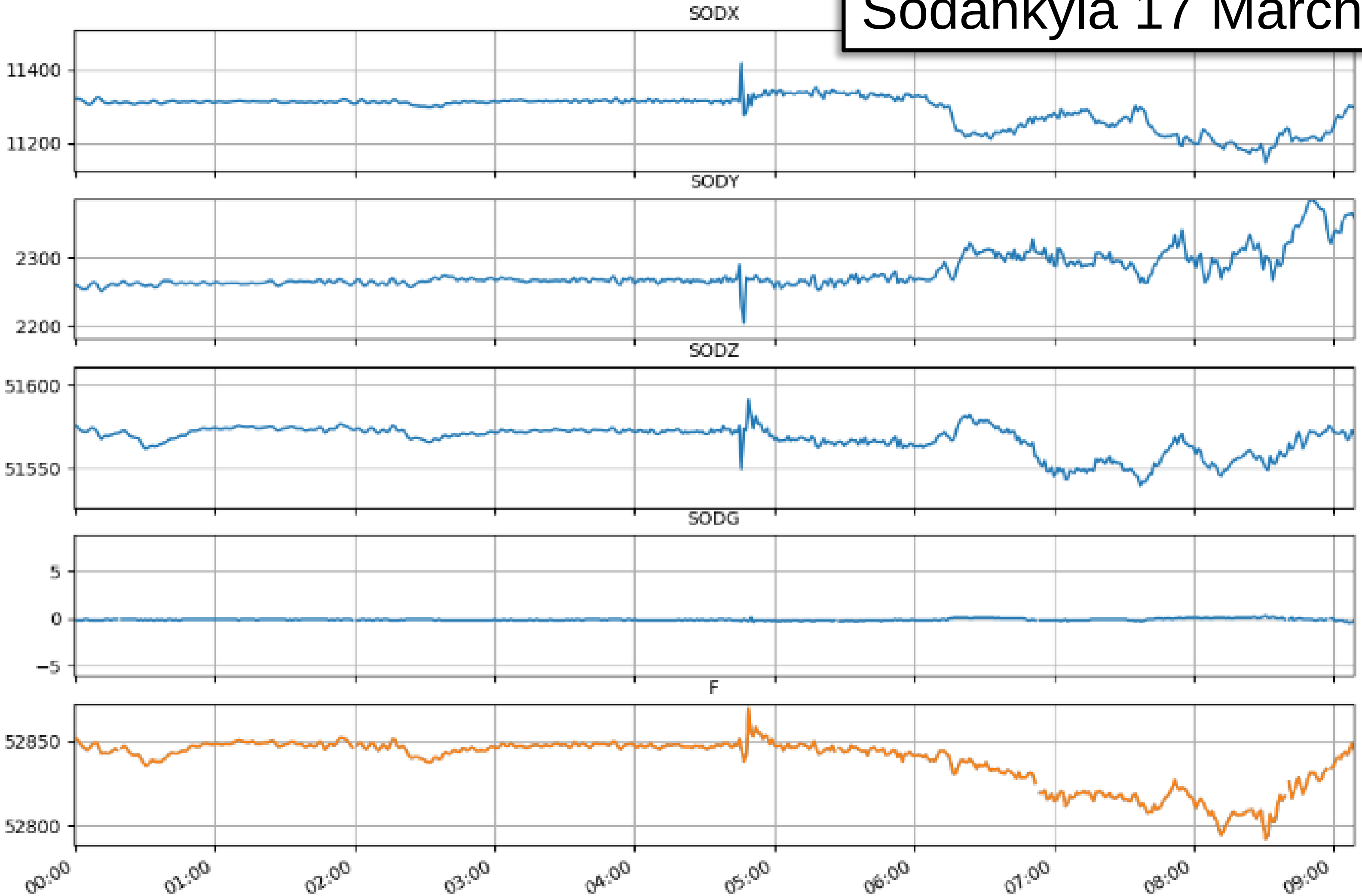
7-8th April 2014
Sarah Reay
Missing data on GDAS-2 proton du … the following morning (10:13UT)

6 May 2014
Stephen Tredwin
Grass cutting around GDAS3 12:00-12:30.

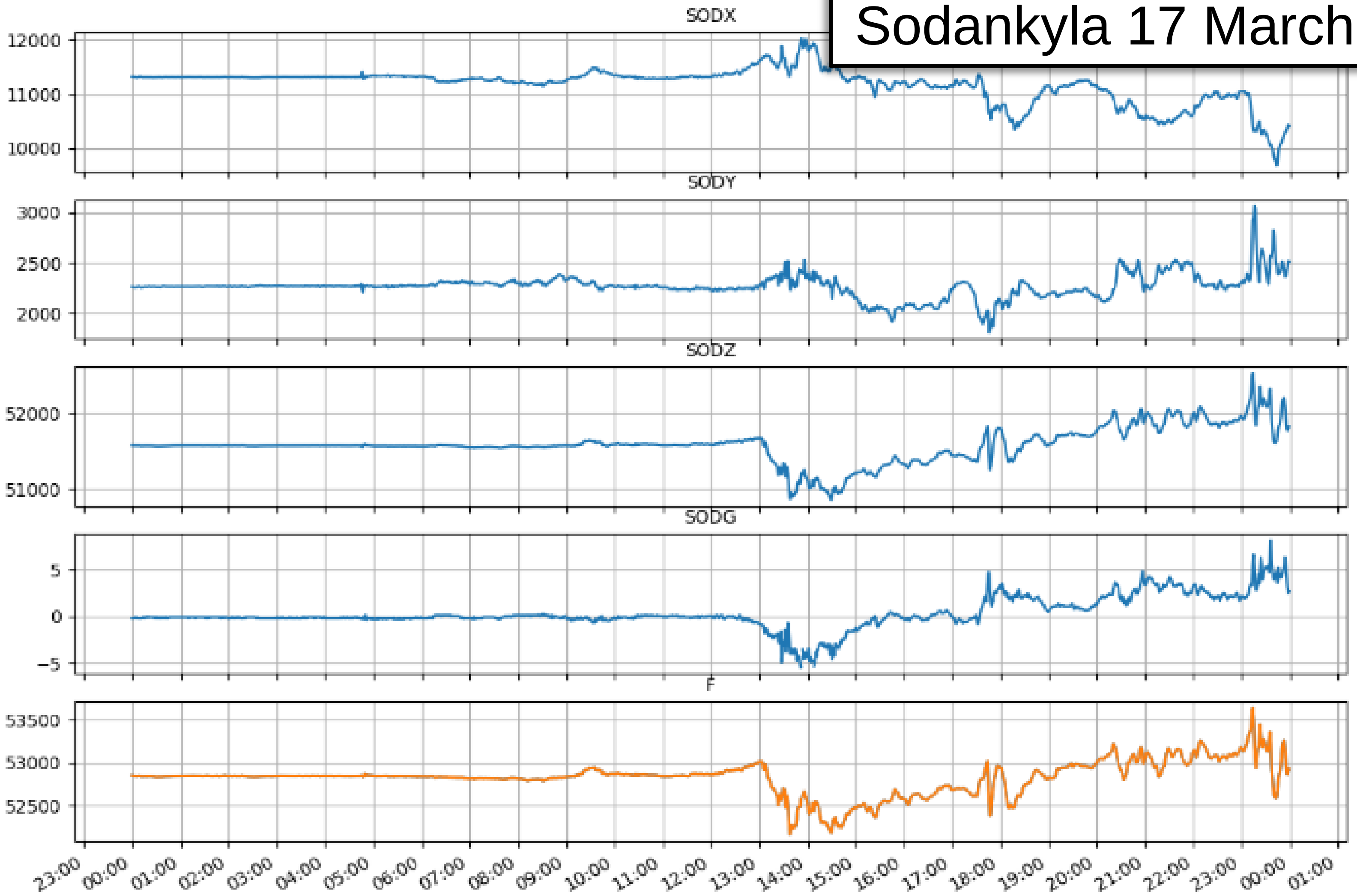
7 May 2014
Ewan Dawson
Service/calibration of GDAS1 & GDAS2 (1000-1245UT), and GDAS3 (afternoon). GDAS1 filled with GDAS3 during calibration.

8 May 2014
Chris Turbitt
Backup satellite network failure at both Hartland and Eskdalemuir occurred the previous night at 2200UT. This was fixed by a reboot of the TooWay satellite modem in the LV Hut and the New Lab respectively.

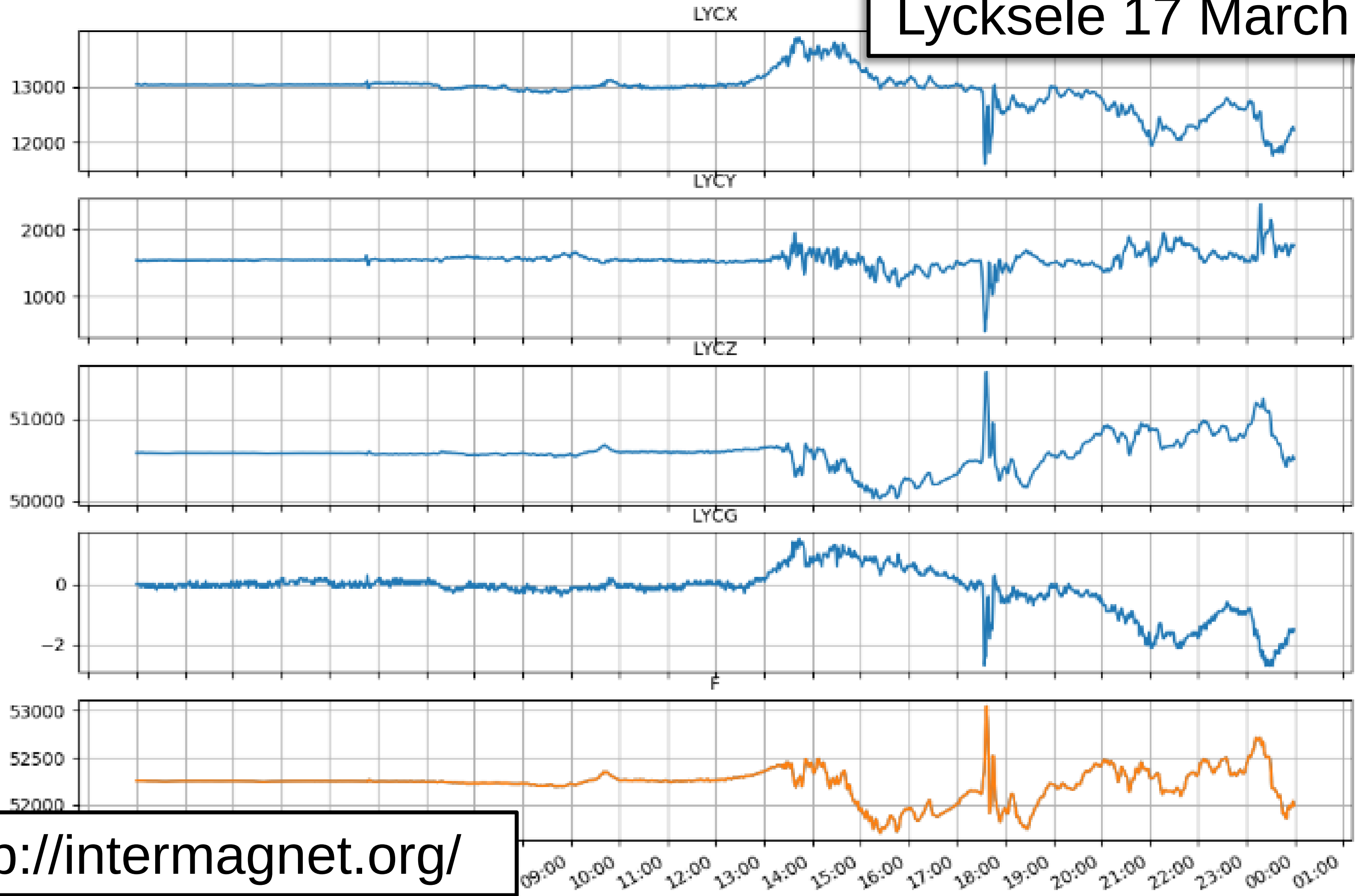
Sodankyla 17 March 2015



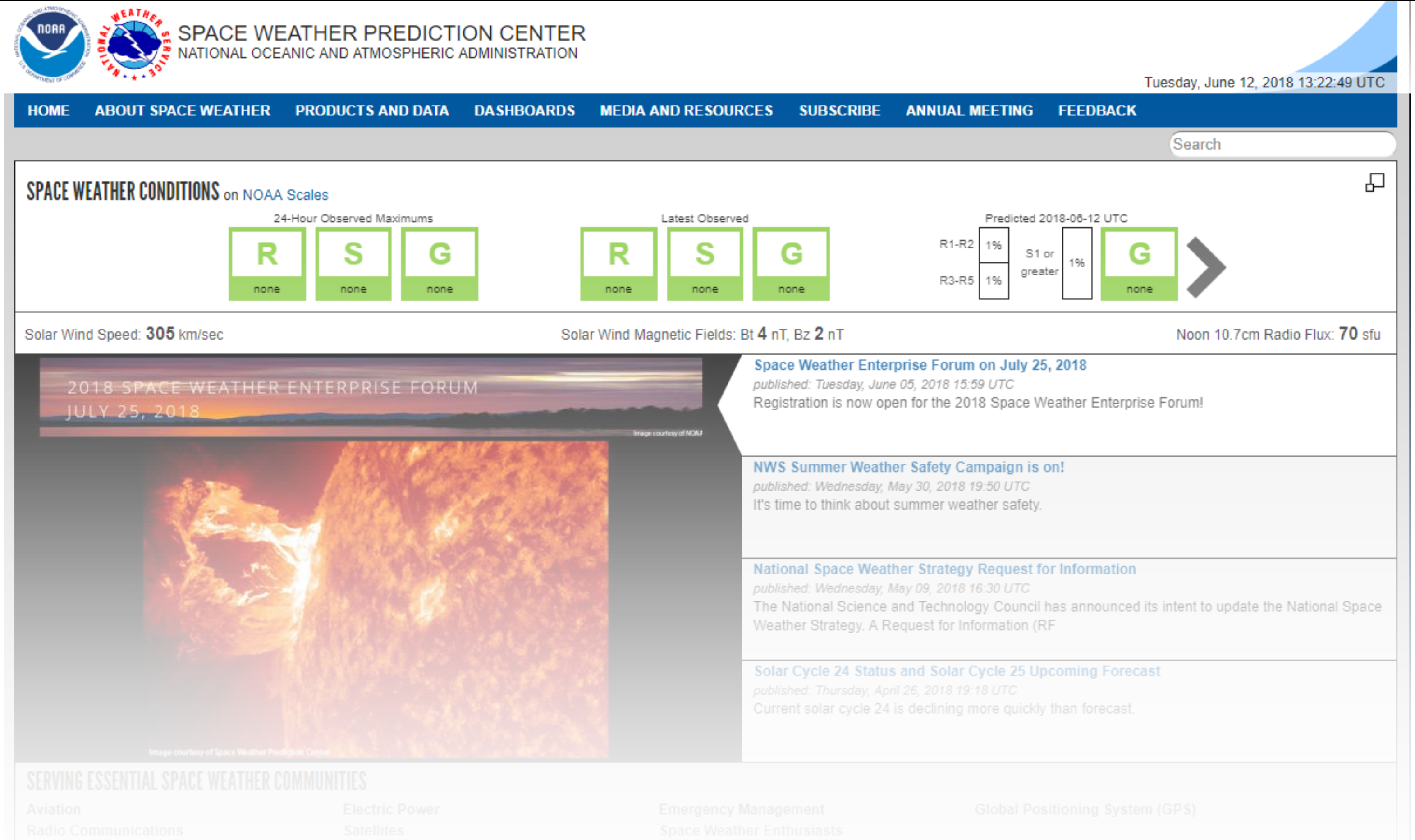
Sodankyla 17 March 2015



Lycksele 17 March 2015

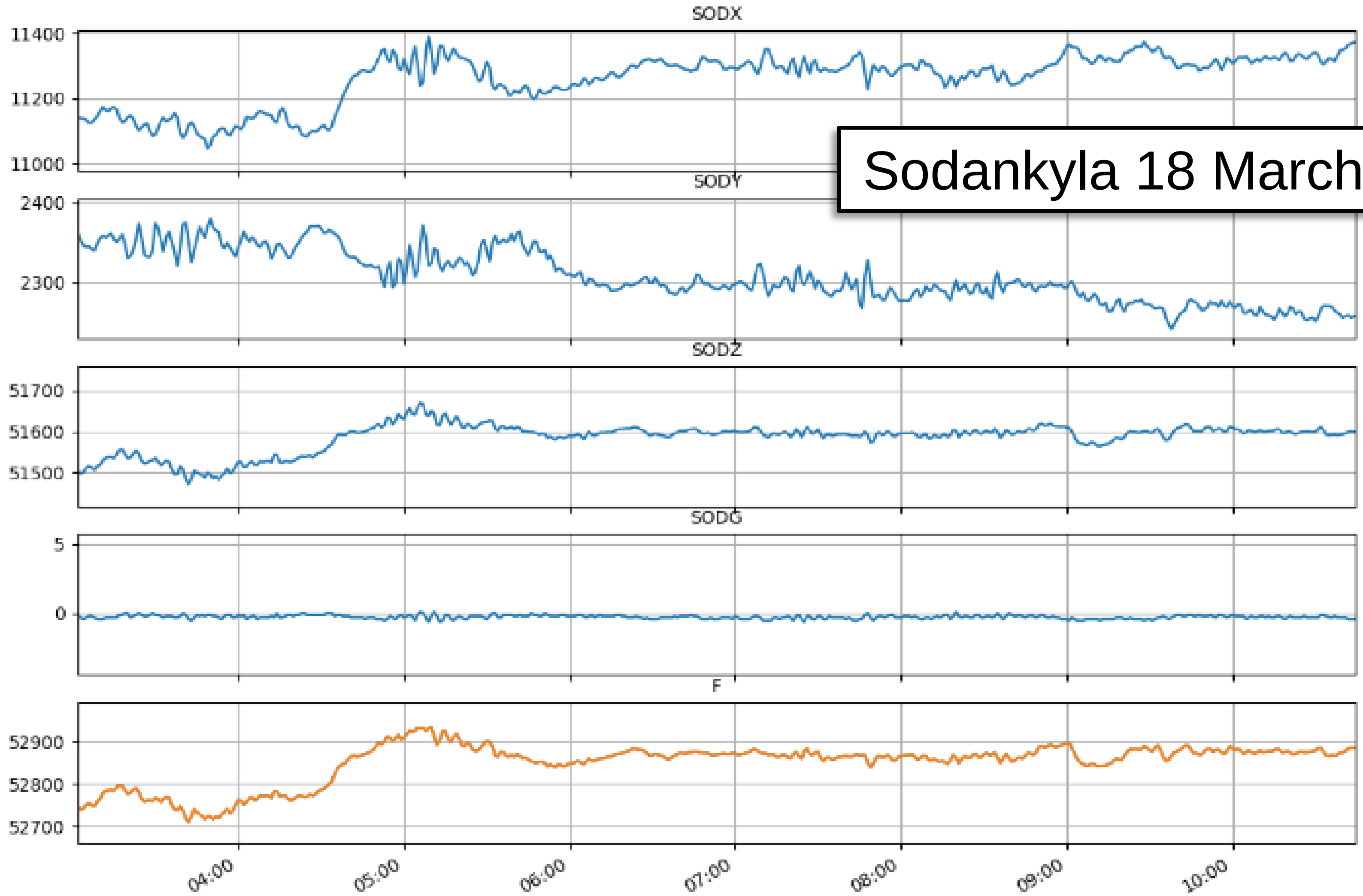


http://intermagnet.org/

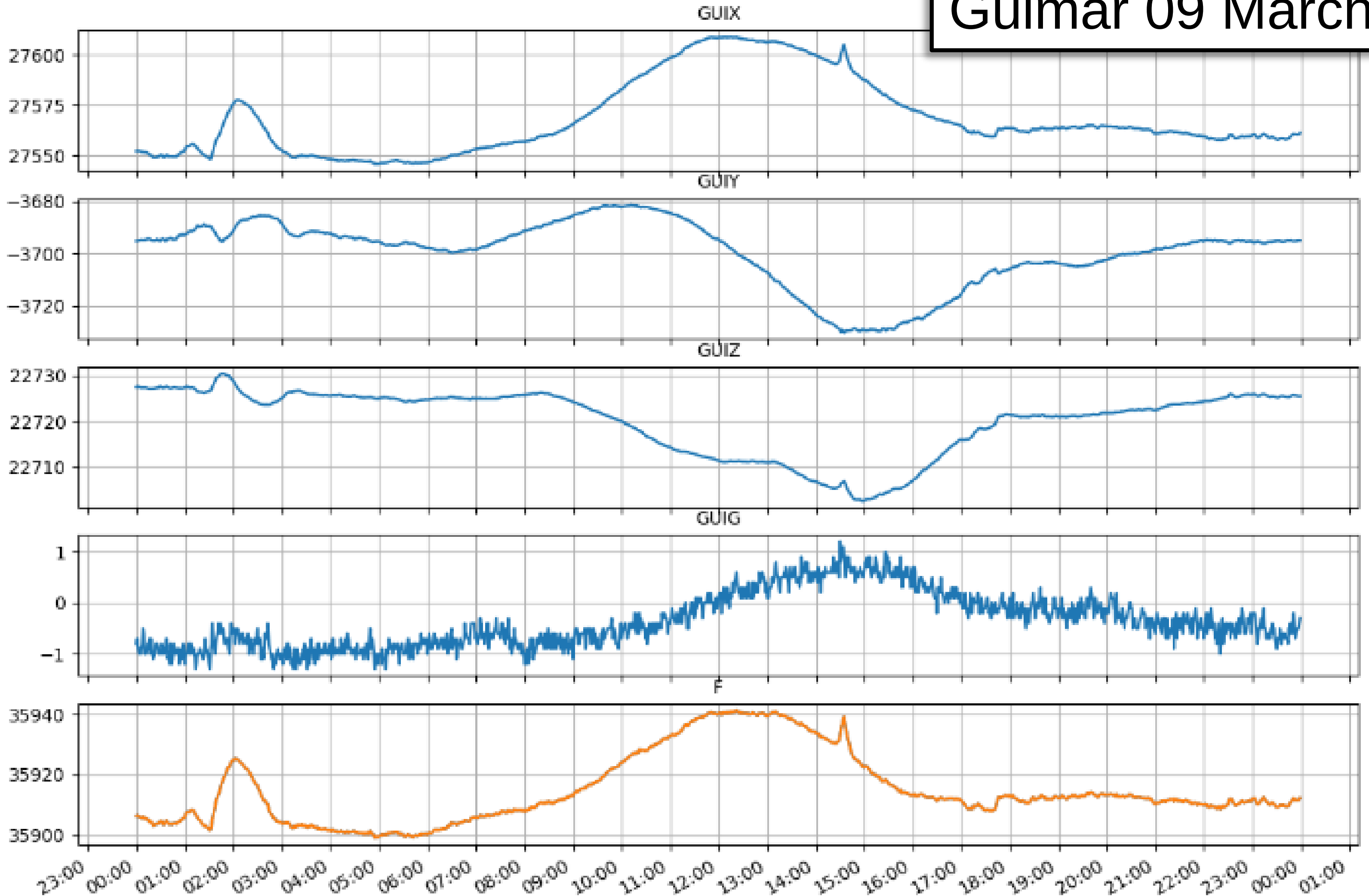


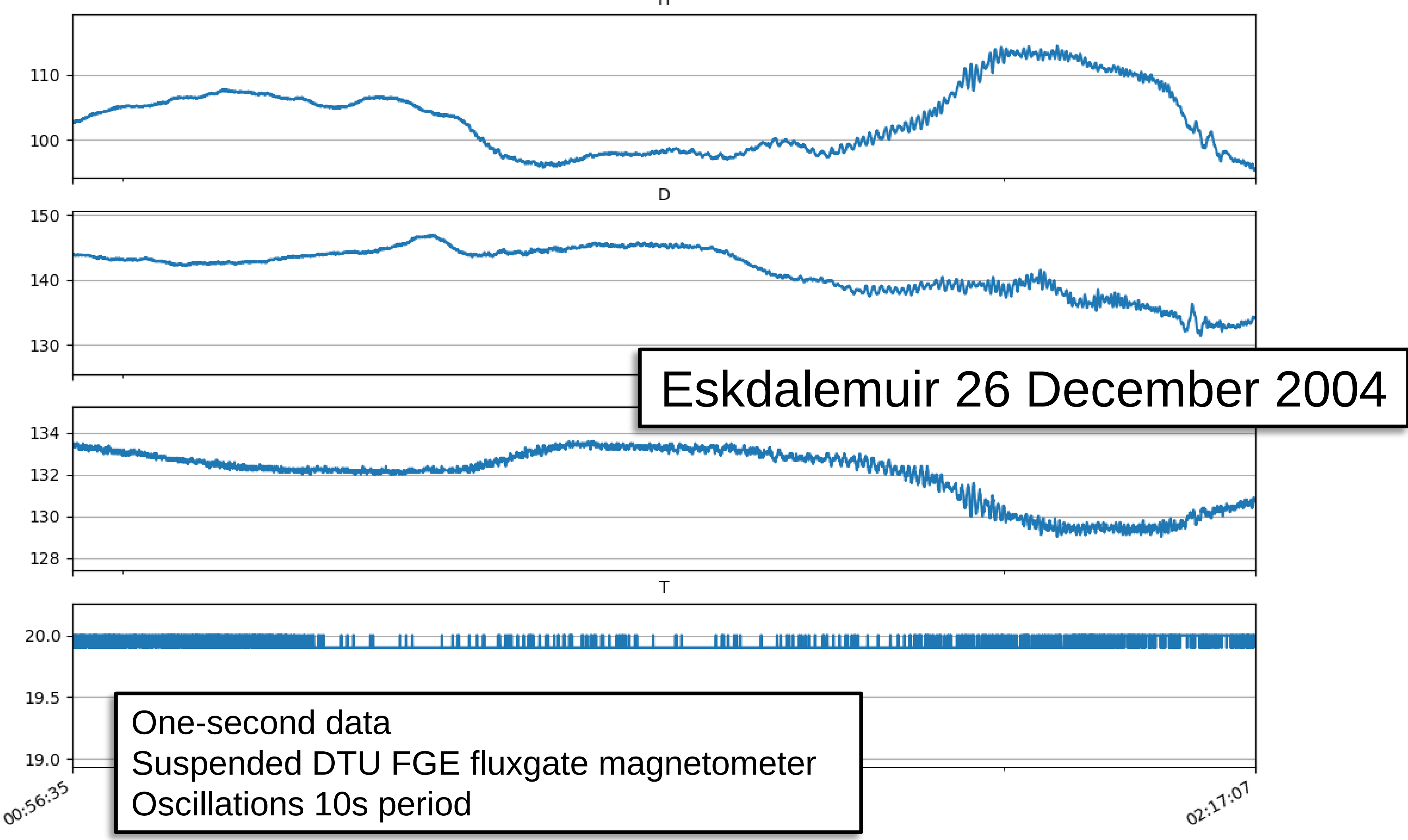
https://www.swpc.noaa.gov/

Sodankyla 18 March 2015



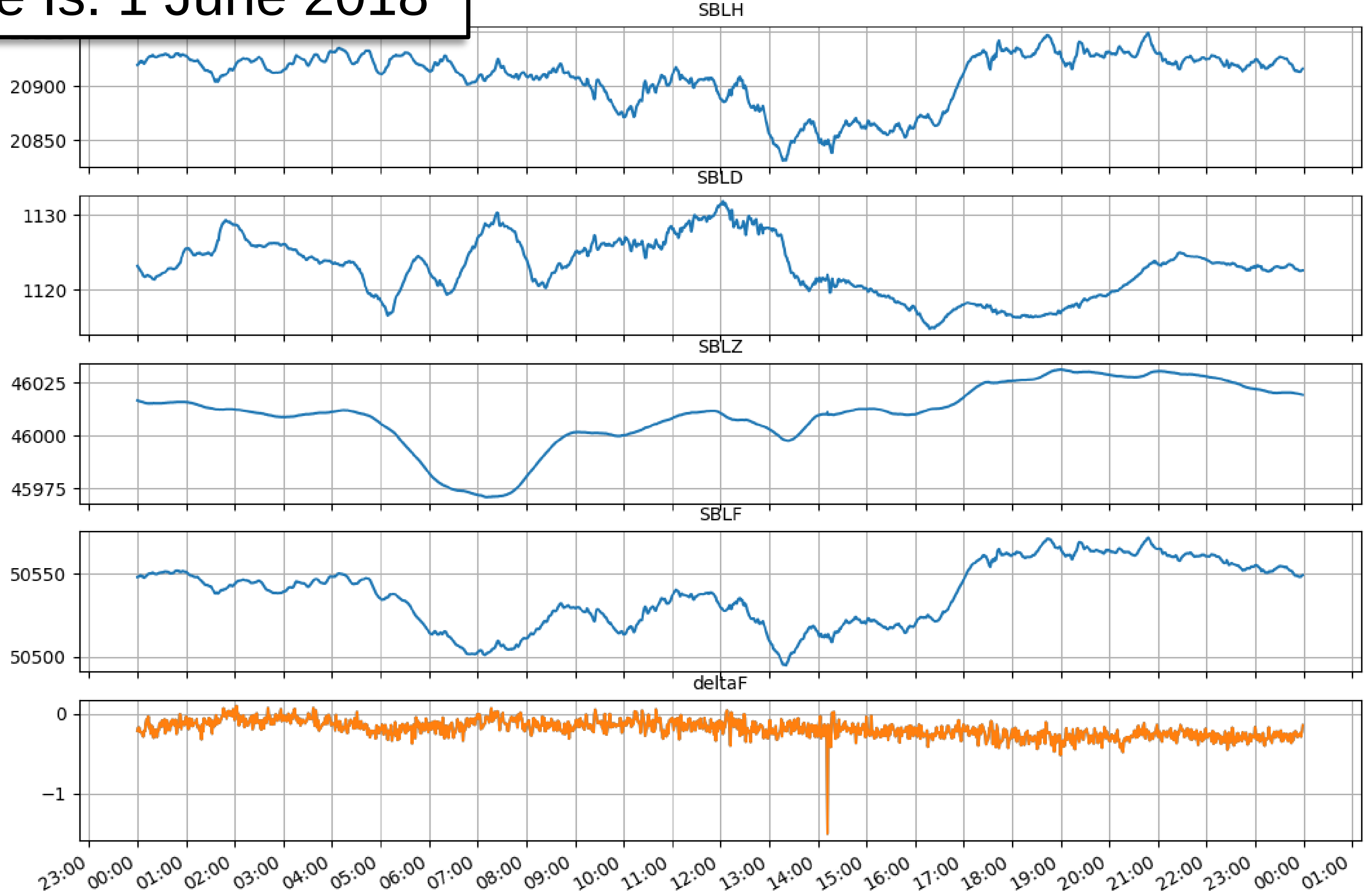
Guimar 09 March 2015



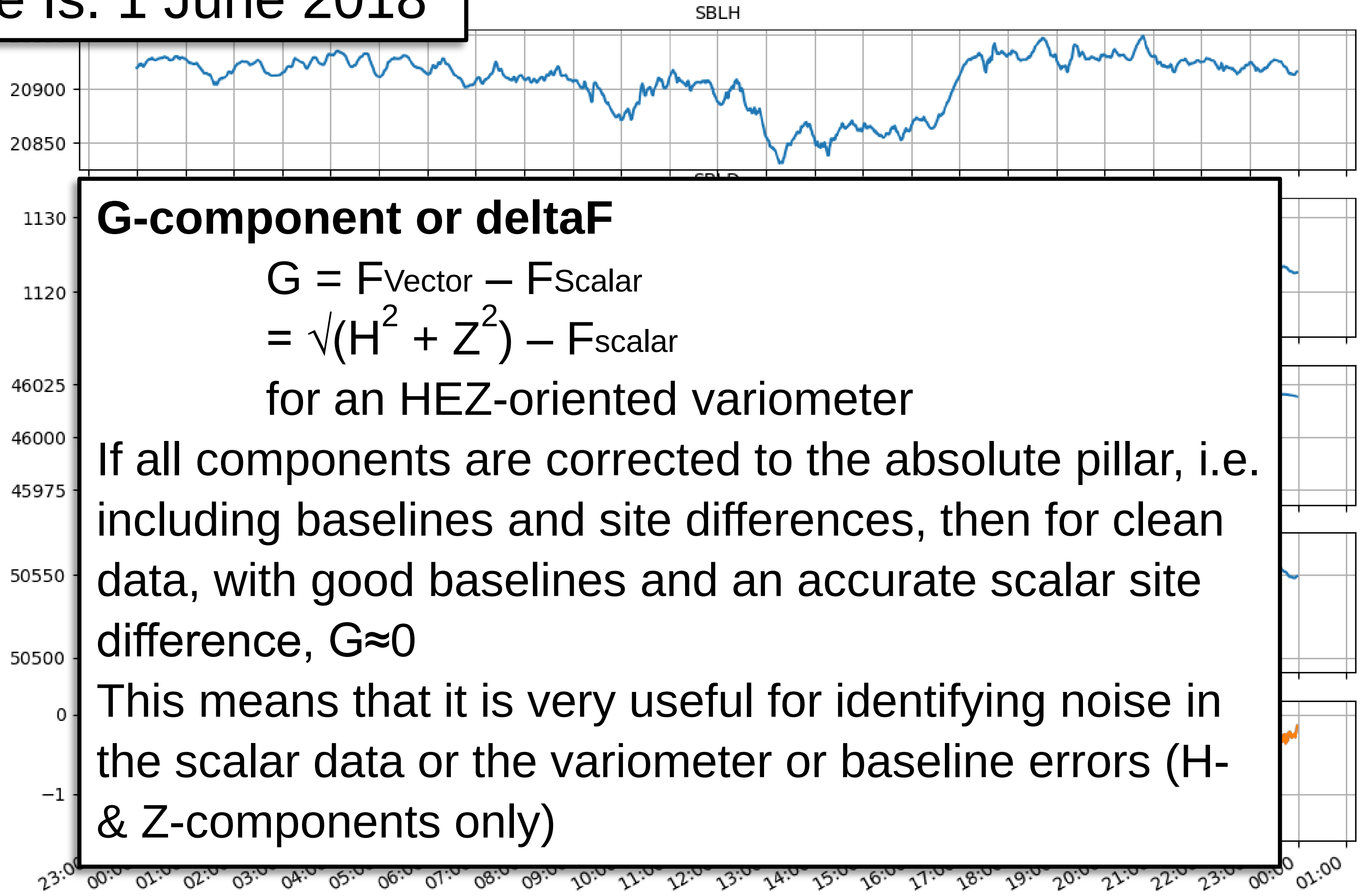


H
110
100
D
150
140
130
134
132
130
128
T
20.0
19.5
19.0
00:56:35
02:17:07
Eskdalemuir 26 December 2004
One-second data
Suspended DTU FGE fluxgate magnetometer
Oscillations 10s period

Sable Is. 1 June 2018



Sable Is. 1 June 2018



G-component or deltaF

$G = F_{Vector} - F_{Scalar}$

$= \sqrt{(H^2 + Z^2)} - F_{scalar}$

for an HEZ-oriented variometer

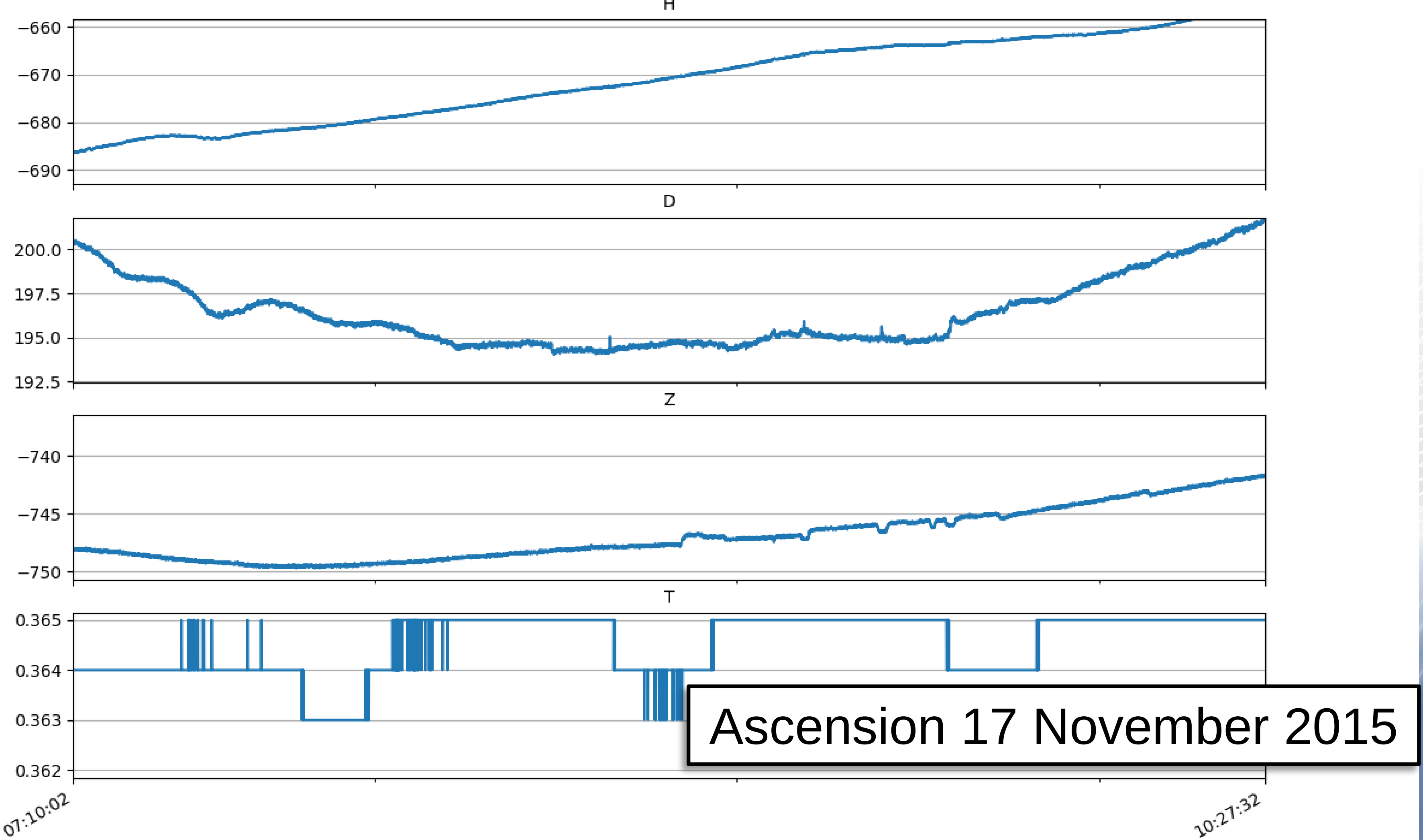
If all components are corrected to the absolute pillar, i.e. including baselines and site differences, then for clean data, with good baselines and an accurate scalar site difference, G≈0

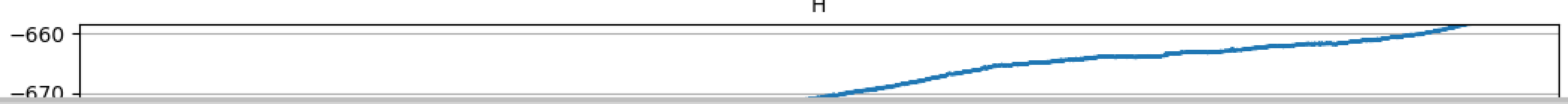
This means that it is very useful for identifying noise in the scalar data or the variometer or baseline errors (H- & Z-components only)

Guidance on Cleaning Variometer Data

- Maintain an observatory diary of instrument modifications, changes around the site, etc.
- Compare instruments and/or observatories on a daily basis to identify steps and jumps
- Make edits to variometer data rather than data with baselines added
- Replace data with those from a clean instrument where available, ensuring data are continuous before and after the gap
- Delete corrupted data by flagging data as missing 99999.0 in IAGA-2002 (88888.0 indicates component not observed/measured)
- Note the IAGA rule on mean calculation for missing data
- Always keep the original data and use a version control and an edit log to keep track of any changes made
- As tempting as it is, don't interpolate missing data!

Ebro Observatory, Spain

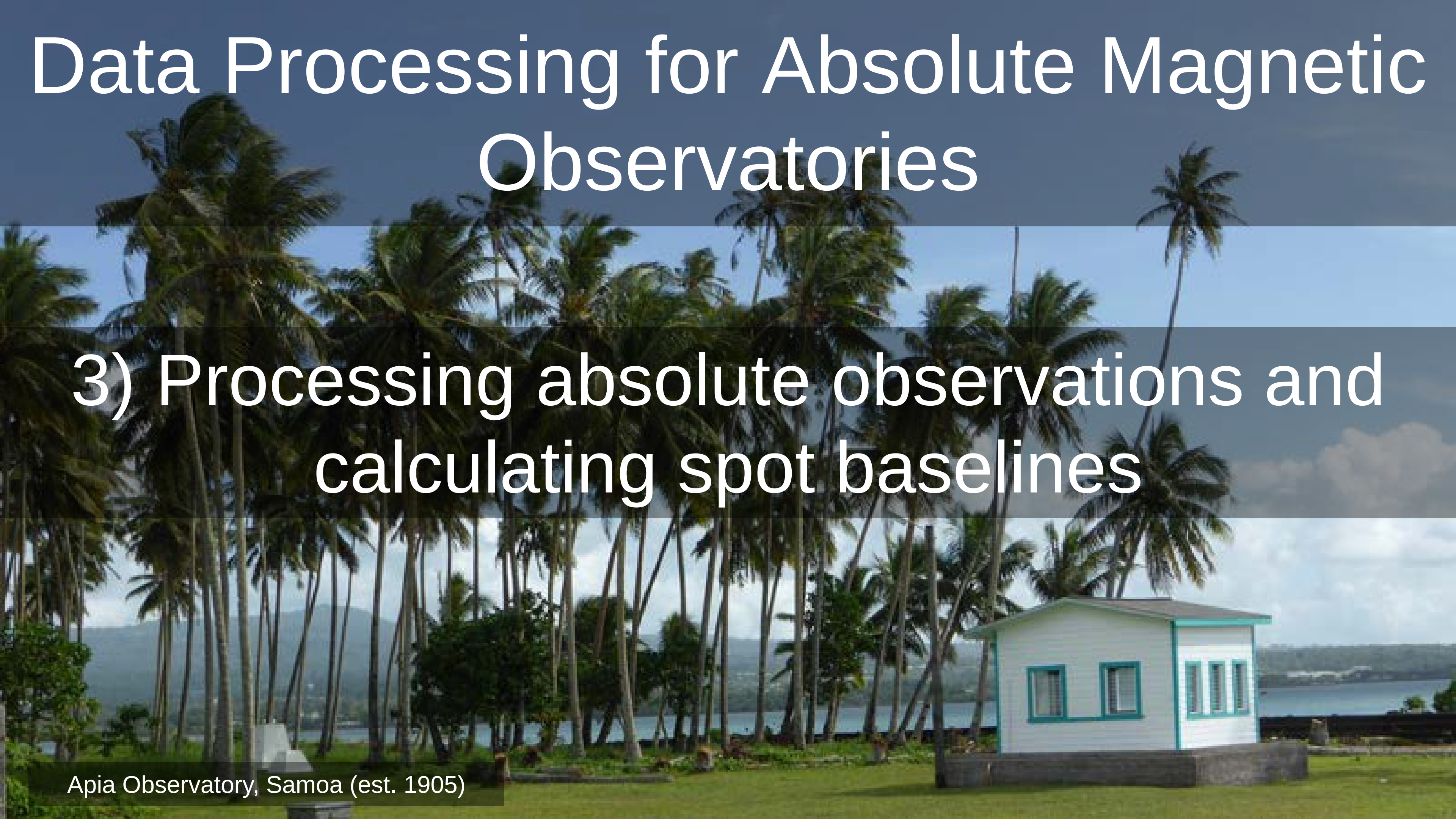

H
−660
−670
−680
−690
D
200.0
197.5
195.0
192.5
Z
−740
−745
−750
T
0.365
0.364
0.363
0.362
07:10:02
10:27:32
Ascension 17 November 2015



Start		End					
Date	Time	Date	Time	Instrument	Reason	Correction Detail	Corrected by
27/11/2015	08:38:45	27/11/2015	08:39:16	F	Corrupt data - vehicle movement	D Flagged	thom2
27/11/2015	09:11:02	27/11/2015	09:11:16	F	Corrupt data - vehicle movement	D Flagged	thom2
27/11/2015	14:05:46	27/11/2015	14:37:53	F	Corrupt data - vehicle movement	D+0.1	thom2
27/11/2015	08:50:40	27/11/2015	08:51:28	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	10:07:52	27/11/2015	10:08:34	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	08:50:51	27/11/2015	10:08:34	F,P	Corrupt data - vehicle movement	Z-0.311,F+0.21	thom2
27/11/2015	08:57:45	27/11/2015	08:58:23	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	08:51:06	27/11/2015	08:58:23	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	09:10:21	27/11/2015	09:10:59	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	08:57:45	27/11/2015	09:10:39	F	Corrupt data - vehicle movement	H+0.135,D+0.029,Z-0.2,F+0.25	thom2
27/11/2015	09:11:38	27/11/2015	09:12:07	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	09:23:04	27/11/2015	09:23:46	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	09:12:01	27/11/2015	09:23:46	F,P	Corrupt data - vehicle movement	H-0.019,D+0.015,Z-0.62,F+0.4	thom2
27/11/2015	09:31:48	27/11/2015	09:33:10	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	09:34:21	27/11/2015	09:36:31	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	09:24:39	27/11/2015	09:25:21	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	09:24:39	27/11/2015	09:35:18	F,P	Corrupt data - vehicle movement	Z+0.6,F+0.25	thom2
27/11/2015	09:42:38	27/11/2015	09:44:30	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	09:36:08	27/11/2015	09:44:30	F	Corrupt data - vehicle movement	H-0.116,D+0.05	thom2
27/11/2015	14:20:31	27/11/2015	14:23:32	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	14:34:15	27/11/2015	14:48:52	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	14:04:58	27/11/2015	14:07:59	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	14:53:39	27/11/2015	14:54:18	F,P	Corrupt data - vehicle movement	Flagged	thom2
27/11/2015	14:06:32	27/11/2015	14:54:18	F,P	Corrupt data - vehicle movement	Z-0.141,F+0.25	thom2

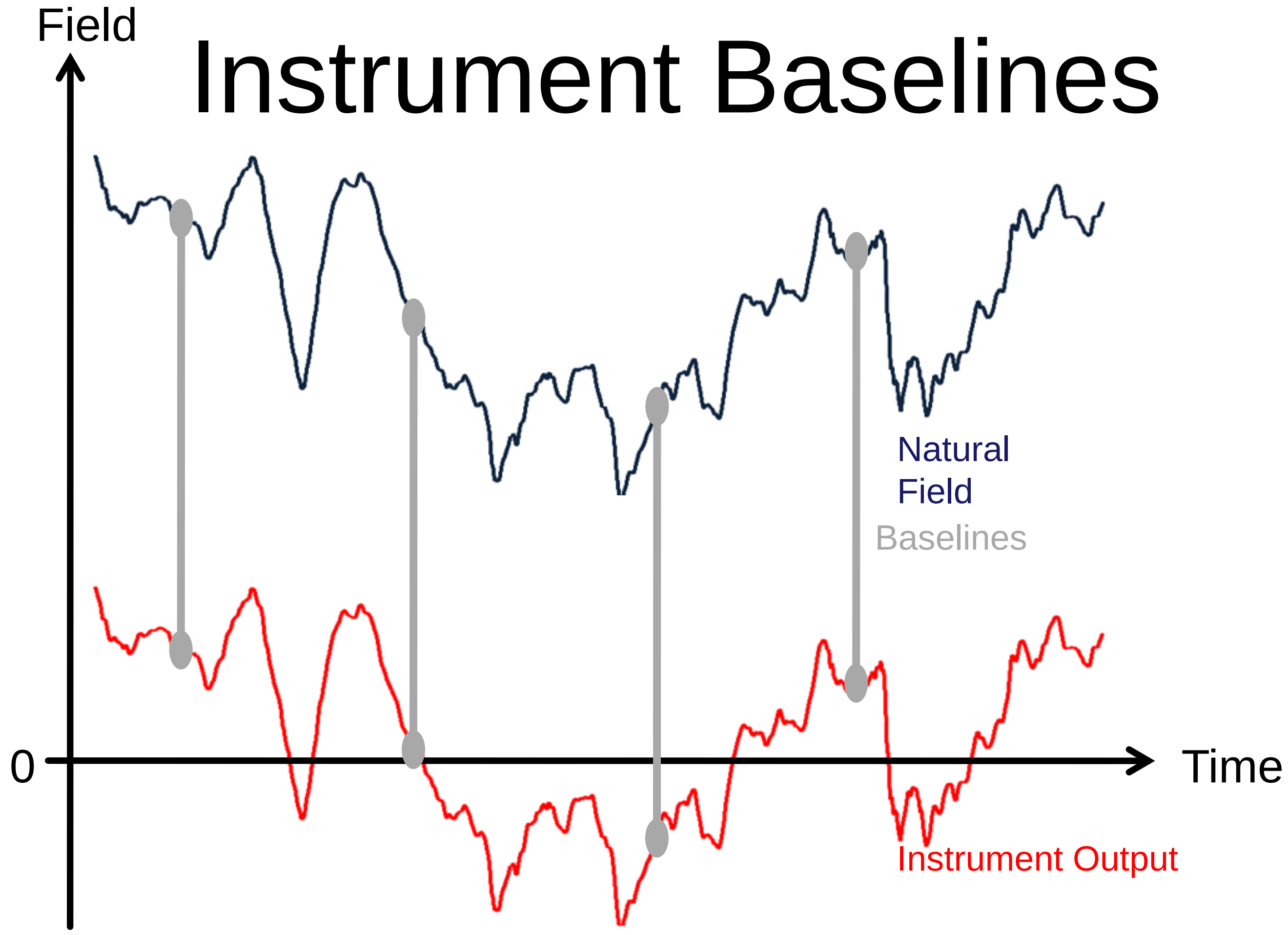
Data Processing for Absolute Magnetic Observatories

3) Processing absolute observations and calculating spot baselines

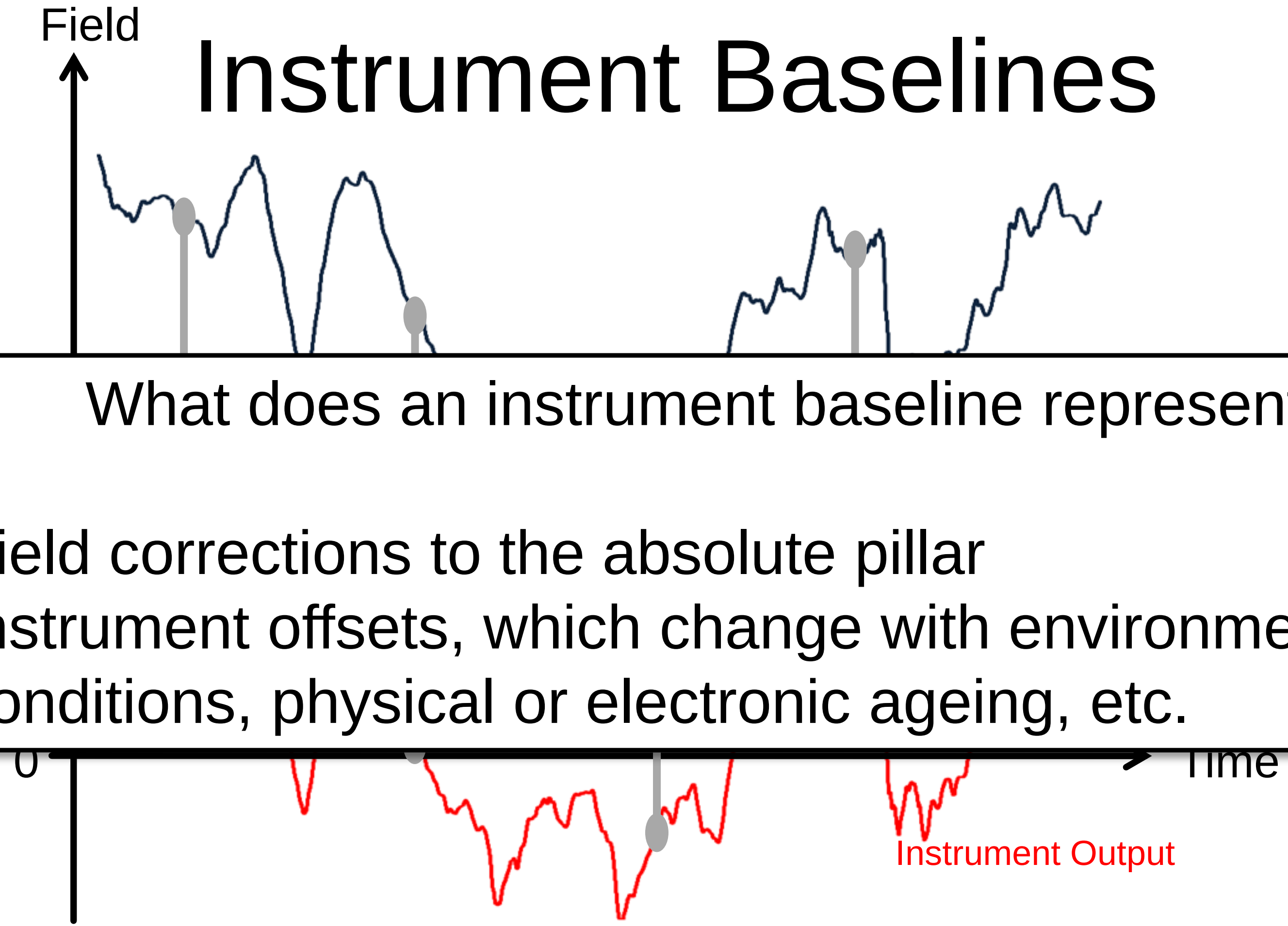


Apia Observatory, Samoa (est. 1905)

Instrument Baselines



Instrument Baselines



What does an instrument baseline represent?

- Field corrections to the absolute pillar
- Instrument offsets, which change with environmental conditions, physical or electronic ageing, etc.

Absolute Observations
Deriving the Field Components

The DI fluxgate-theodolite measures declination & inclination at the absolute pillar (D_A & I_A)

A remote scalar magnetometer provides total field at a separate measuring location, hence F_A at the absolute pillar is:

$$F_A = F_S + s$$

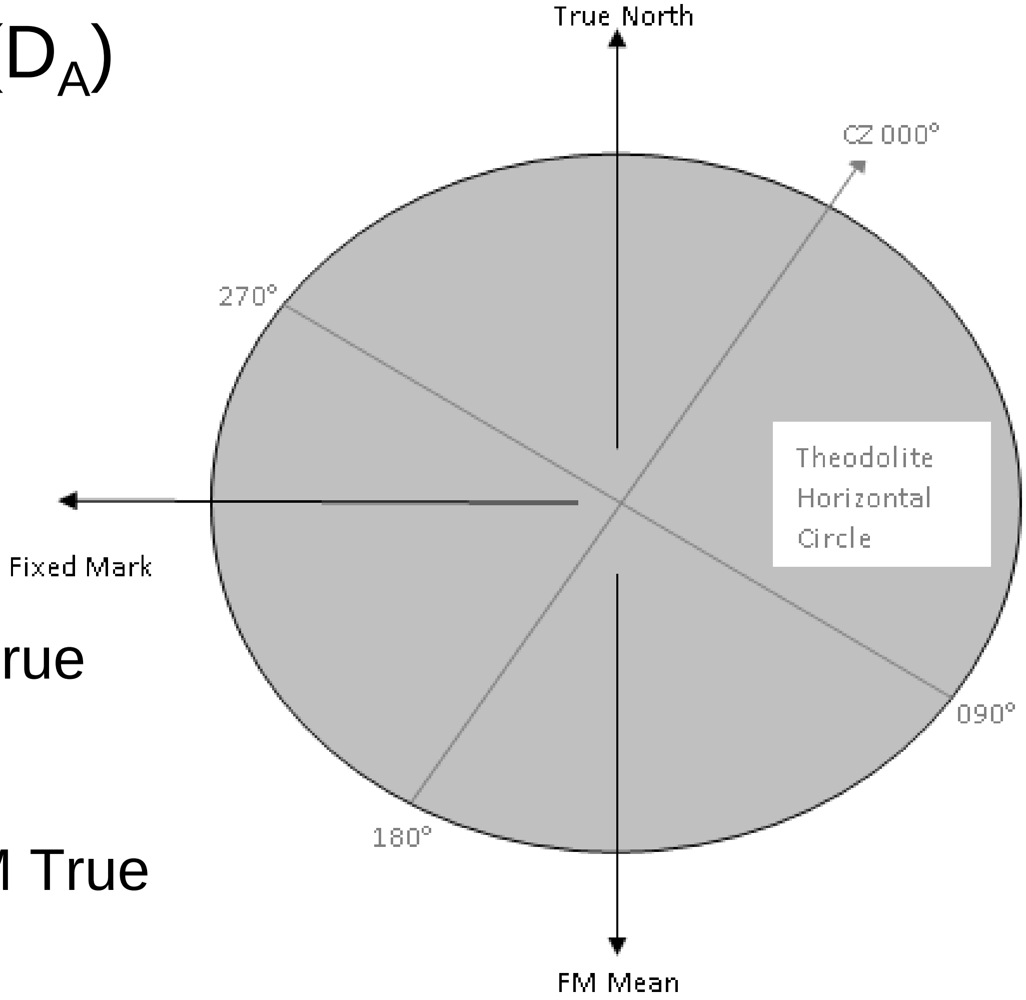
where s is the total field (scalar) site difference between the absolute pillar and the scalar magnetometer (absolute pillar – scalar magnetometer).

If F_A & I_A are measured at the same time, the horizontal and vertical field intensities at the absolute pillar are given by:

$$H_A = F_A .\cos I_A$$

$$Z_A = F_A .\sin I_A$$

Calculating Declination (D_A)



1. Establish the theodolite's True North Circle Reading:
TN Circle =

$$090° + \text{FM Mean} - \text{FM True}$$

Calculating Declination (D_A)

2. Mean the four declination measurements:

$D_{mean} = (WU + WD + EU + ED)/4$

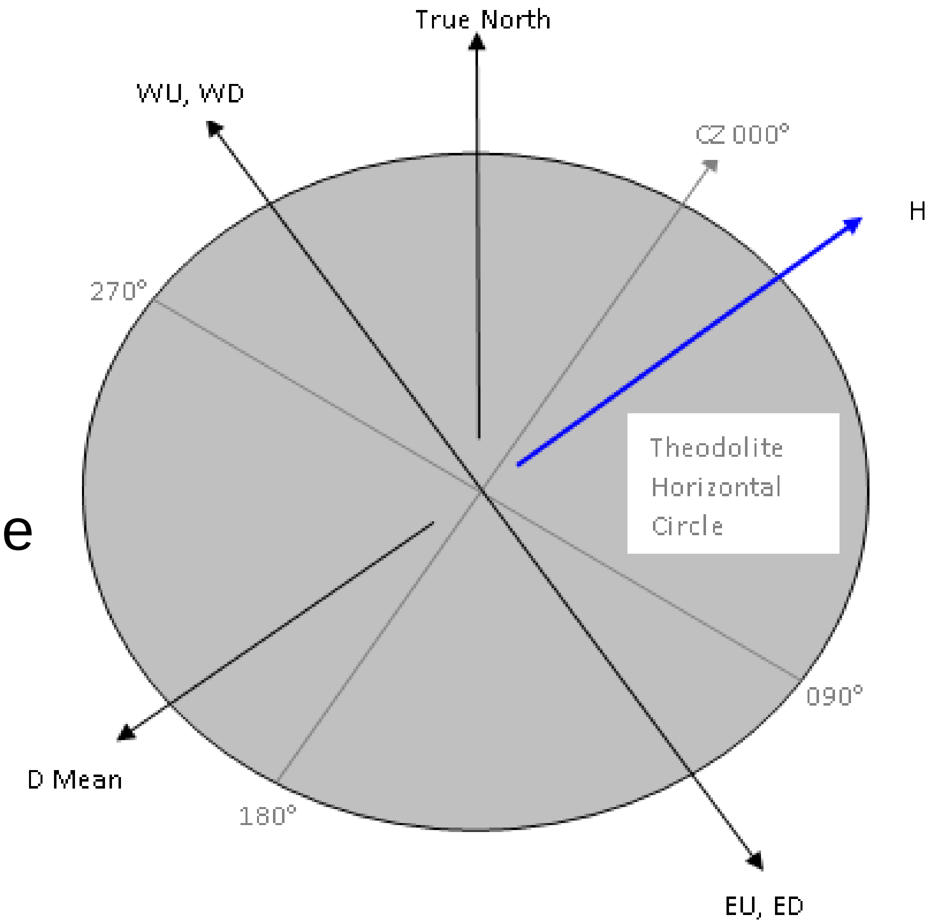
3. Convert from the theodolite's circle reading to geographic coordinates:

$D_A = D_{mean} - \text{TN Circle}$

Note: unless close to the poles,

$-90° < D_A < +90°$

So it may be necessary to add or subtract 180 ° to D_A



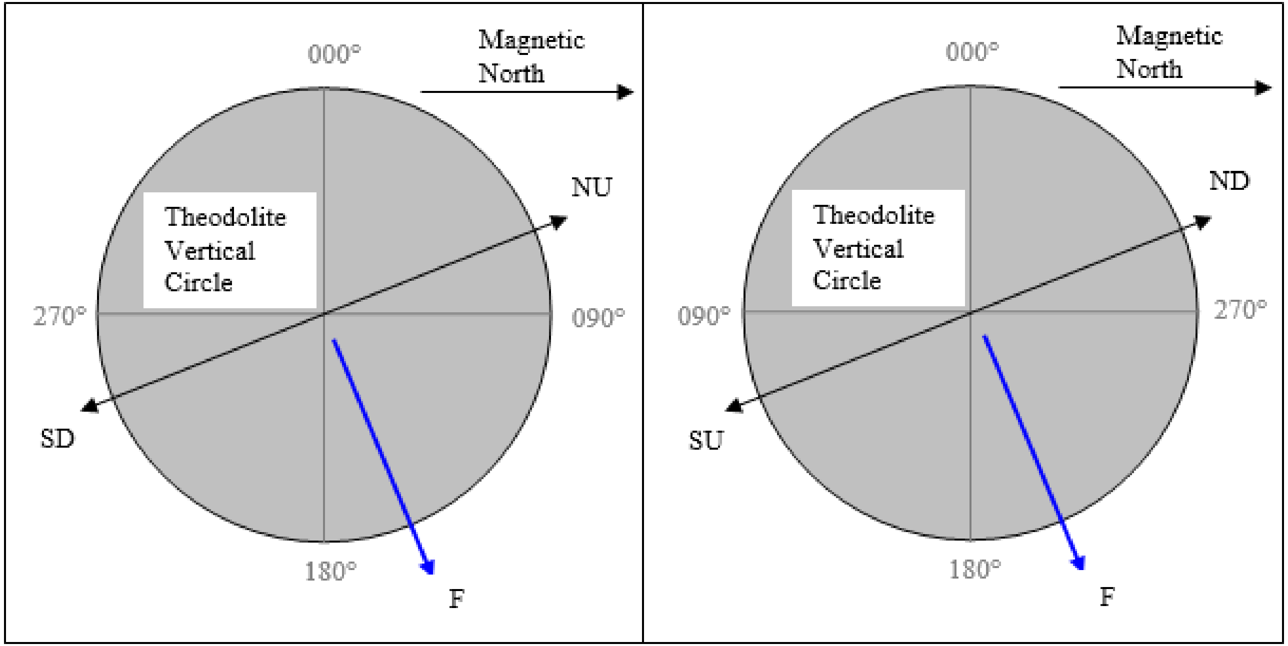
In the northern geomagnetic hemisphere:

Calculating Inclination (I_A)

I_{NU} = NU
I_{SD} = SD - 180°
I_{ND} = 360° - ND
I_{SU} = 180° - SU

& southern hemisphere:

I_{NU} = NU - 180°
I_{SD} = SD - 360°
I_{ND} = 180° - ND
I_{SU} = 0° - SU



I_A = $(I_{NU} + I_{NU} + I_{NU} + I_{NU})/4$

Absolute Observations – Collimation Angles & Offsets

δ is the angle that the that the measurement axis of the magnetometer makes with the optical axis of the telescope in the horizontal plane:

$$\delta_D = (ED + WD - EU - WU) / 4$$

ε is the angle that the measurement axis of the magnetometer makes with the optical axis of the telescope in the vertical plane:

From declination measurements: if (WD+EU) > (ED+WU);

$$\varepsilon_D = (WD + EU - ED - WU - 360°) / (4 * \tan I)$$

otherwise;

$$\varepsilon_D = (WD + EU - ED - WU + 360°) / (4 * \tan I)$$

also from inclination measurements:

$$\varepsilon_I = (ND + SU - NU - SD) / 4$$

z_0 is the fluxgate magnetometer offset:

$$z_{D0} = H \sin [(ED + EU - WD - WU) / 4]$$

$$z_{I0} = F \sin [(SD + SU - ND - NU) / 4]$$

Kerridge, D., J., Theory of the Fluxgate-Theodolite, British Geological Survey Report Number WM/88/14

Absolute Observations – Collima

δ is the angle that the that the measurement axis of the makes with the optical axis of the telescope in the horiz

$$\delta_D = (ED + WD – EU – WU) / 4$$

ε is the angle that the measurement axis of the magnet the optical axis of the telescope in the vertical plane:

From declination measurements: if (WD+EU)

$$\varepsilon_D = (WD + EU – ED – WU - 360°) /$$

otherwise;

$$\varepsilon_D = (WD + EU – ED – WU + 360°)$$

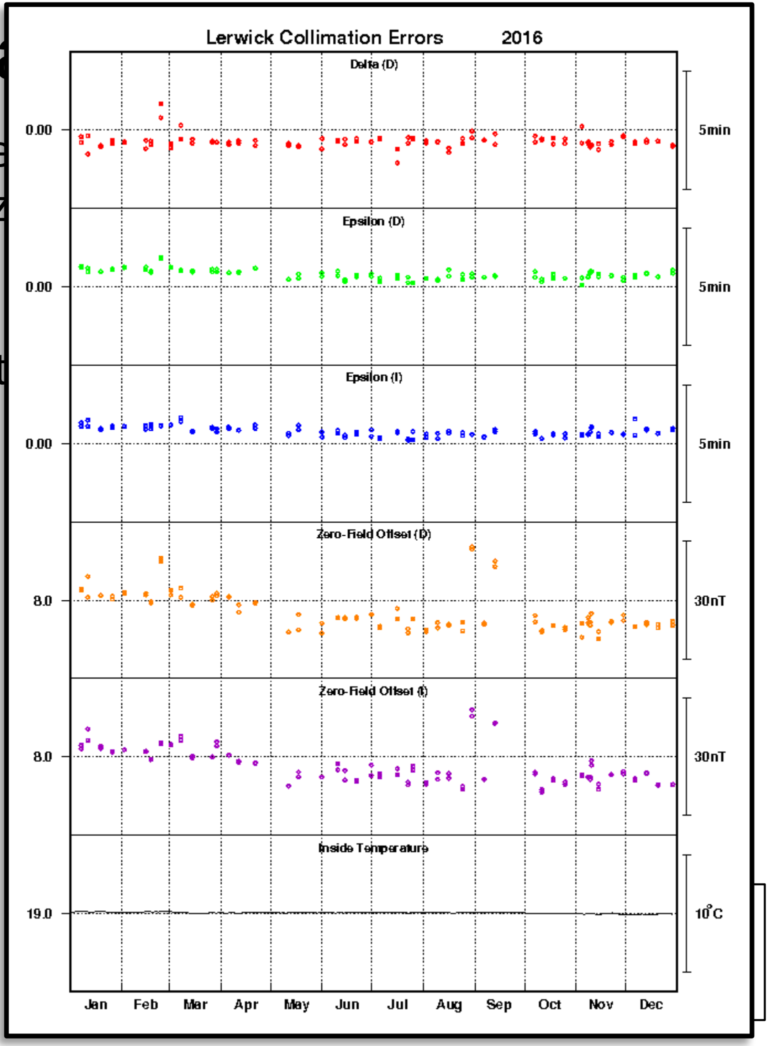
also from inclination measurements:

$$\varepsilon_I = (ND + SU – NU – SD) / 4$$

z_0 is the fluxgate magnetometer offset:

$$z_{D0} = H \sin [(ED + EU – WD - WU) / 4]$$

$$z_{I0} = F \sin [(SD + SU – ND - NU) / 4]$$



Deriving instantaneous variometer baselines

There are a many different variometer types, with an infinite number of orientations:

HEZ XYZ DIF ABZ…

Hence, it is not possible to cover all cases. Here we will use an HEZ oriented fluxgate magnetometer that has had bias fields applied to the H- and Z-sensor at the time of set-up (t_0).

To derive baselines for any variometer, we have to make assumptions about its orientation and set-up. For our HEZ magnetometer, we will assume that it has been manufactured and installed such that the Z-sensor is vertical, the H- and E-sensors are in the horizontal and all three sensors are close to perpendicular. It is also manufactured such that the zero-field offset on the E-sensor is very low.

Deriving instantaneous variometer baselines

Vertical Component Baseline

If $Z_A(t)$ is the vertical component determined by an absolute observation at time t , then any difference between $Z_A(t_1)$ and the variometer data at that time $Z_V(t)$ is due to the instrument offset & bias $Z_O(t)$ and the site difference in the vertical component between the absolute pillar and the sensor $Z_D(t)$:

$$Z_A(t) - Z_V(t) = Z_O(t) - Z_D(t)$$

The offset and site difference can be combined into a single vertical component baseline (Z_B):

$$\mathbf{Z_B(t) = Z_A(t) - Z_V(t)}$$

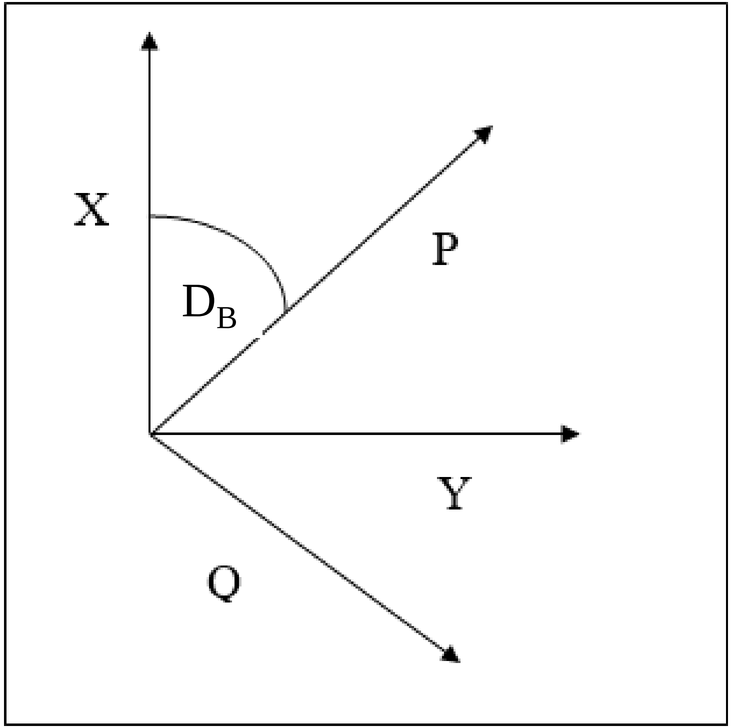
Note that the time of the inclination measurement is the average time of the four inclination circle readings. To allow comparison, $Z_V(t)$ has to be calculated as the <u>average</u> of four variometer values whose <u>times match</u> those of the circle readings.

Deriving instantaneous variometer baselines

Horizontal Component Baseline

At the time of set-up (t_0), the sensor was oriented such that the E-sensor is eastward and nulled (or close to) without bias field. This aligns the E-sensor close to magnetic east and the H-sensor close to magnetic north. The exact orientation of the H-sensor in the horizontal plane is given by the declination offset D_B.

At a later time, the H- and E- sensors will no longer be aligned with the H- and E- components so, to avoid confusion, we will label them P- & Q-sensor respectively.



P- and Q-sensor orientation in the horizontal plane

Deriving instantaneous variometer baselines

Horizontal Component Baseline

The derivation of the H baseline is similar in principle to the Z baseline, but the calculation of the H-component from the variometer is complicated by the fact that at any time after t_0, neither sensor can be assumed to be aligned along the H vector. Instead, H_S – the horizontal intensity at the sensor - is calculated from the vector sum of the components along the two sensors P and Q. At time t:

$$H_S^2(t) = P_S(t)^2 + Q_S(t)^2$$

Including the sensor offsets P_O & Q_O, $H_S^2(t)$ can be defined in terms of the variometer outputs P_V & Q_V:

$$H_S^2(t) = (P_V(t) + P_O(t))^2 + (Q_V(t) + Q_O(t))^2$$

Deriving instantaneous variometer baselines

Horizontal Component Baseline

Including site correction terms between the variometer sensor and the absolute pillar P_D & Q_D:

$$H_A^2(t) = (P_V(t) + P_O(t) + P_D(t))^2 + (Q_V(t) + Q_O(t) + Q_D(t))^2$$

Since the magnetometer is manufactured such that $Q_O \approx 0$ and if we assume that the observatory site is chosen such that the gradients are low, the value of $P_V(t) + P_O(t)$ dominates H_S and we can approximate the above equation to:

$$H_A^2(t) = (P_V(t) + P_B(t))^2 + (Q_V(t))^2$$

Where $P_B(t) = P_O(t) + P_D(t)$. Since Q_V is small, P_B is commonly referred to as the horizontal component baseline:

$$\mathbf{H_B(t) = (H_A(t)^2 - Q_V(t)^2)^{1/2} - P_V(t)}$$

Again $P_V(t)$ & $Q_V(t)$ are the <u>averages</u> of four variometer values whose <u>times match</u> those of the inclination circle readings.

Deriving instantaneous variometer baselines

Declination Baseline

$D_{B'}(t)$, is an angle describing the orientation with respect to true north of the P-sensor of an imaginary variometer located at the absolute pillar:

$$D_A(t) = D_{B'}(t) + \sin^{-1}[(Q_V(t) + Q_O(t) + Q_D(t)) / H_A(t)]$$

For small values of $Q_V(t_1)$, $Q_V(t_1)$ & $Q_D(t_1)$, this approximates to:

$$D_A(t) =$$

$$D_{B'}(t) + \sin^{-1}[Q_V(t) / H_A(t)] + \sin^{-1}[Q_O(t) / H_A(t)] + \sin^{-1}[Q_D(t) / H_A(t)]$$

$$= D_{B'}(t) + \sin^{-1}[Q_V(t) / H_A(t)] + D_O(t) + D_D(t)$$

Putting $D_{B'}$, D_O & D_D together into one declination baseline term:

$$\mathbf{D_B(t) = D_A(t) - \sin^{-1}[Q_V(t) / H_A(t)]}$$

$Q_V(t)$ is an <u>average</u> of the four variometer values whose <u>times match</u> those of the declination circle readings. Note: $H_A(t)$ isn't strictly coincident with $Q_V(t)$ but is a sufficiently good approximation if measured during the same observation.

Absolute Observation Record*

```
Observatory: BGS Test
Logger: bgs
Observer: NB
Date: 11 May 2014
Site Difference:    -31.5
Theodolite serial number: 327865
Theodolite vertical scale offset:     0
Fluxgate serial number: 886H

FIXED MARK READING
        CR 1:         033°  17'  00"
        CL 1:         213°  16'  54"
        CR 2:         033°  17'  00"
        CL 2:         213°  16'  48"
        Mean:         123°  16'  55"
     FM True:         282°  15'  24"
   TN Circle:         111°  01'  32"

DECLINATION OBSERVATION
                                                            VarD(nT)
          WU: 18:19   204°  10'  12"   204.1700°                45.3
          ED: 18:20   204°  05'  30"   204.0917°                45.3
          WD: 18:21   024°  11'  30"    24.1917°                45.4
          EU: 18:22   024°  05'  30"    24.0917°                45.4
        Mean: 18:20   114°  08'  10"

 Declination: 18:20   003°  06'  39"     3.1108°

INCLINATION OBSERVATION
                                                   PPMF(nT) VarH(nT) VarZ(nT)
          NU: 18:25   130°  14'  42"   -49.7550°    28470.0    -60.7    -17.1
          SD: 18:26   310°  17'  00"   -49.7167°    28469.9    -60.6    -17.1
          ND: 18:27   229°  46'  24"   -49.7733°    28470.0    -60.6    -17.2
          SU: 18:28   049°  42'  00"   -49.7000°    28469.9    -60.7    -17.1

 Inclination: 18:26  -049°  44'  11"   -49.7362°

BASELINES

          Absolute      GDAS  Baseline
F (nT):    28438.4   28469.9     -31.5
D(deg):     3.1108    0.1414    2.9695  002°  58'  10"
H (nT):    18380.0     -60.6   18440.6
Z (nT):   -21700.7     -17.1  -21683.6
I (deg):  -49.7362

COLLIMATION ERRORS

Declination Delta:     000°  00'  20"
Declination Epsilon:   000°  00' -17"
Declination Zo (nT): -14.3
Inclination Epsilon:   000°  00' -02"
Inclination Zo (nT): -13.9
```

*this is a sample of a null-method record used by BGS. Each observatory will have a different form of this record.

Note: some observatories use the residual method for observing, in which case a record is also made of the fluxgate-theodolite magnetometer output (m_r) and the circle readings are then adjusted by a factor of

$\sin^{-1}[m_r / H]$ for declination

$\sin^{-1}[m_r / F]$ for inclination

Observatory: BGS Test

Header

Logger: bgs

Observer: NB

Date: 11 May 2014

Site Difference: -31.5

Theodolite serial number: 327865

Theodolite vertical scale offset: 0

Fluxgate serial number: 886H

FIXED MARK READING

CR 1:	033°	17'	00"
CL 1:	213°	16'	54"
CR 2:	033°	17'	00"
CL 2:	213°	16'	48"
Mean:	123°	16'	55"
FM True:	282°	15'	24"
TN Circle:	111°	01'	32"

Absolute Observation Record*

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Note: some observatories use the residual method for observing, in which case a record is also made of the fluxgate-theodolite magnetometer output (m_r) and the circle readings are then adjusted by a factor of

$\sin^{-1}[m_r / H]$ for declination

$\sin^{-1}[m_r / F]$ for inclination

Observatory: BGS Test

Declination & Inclination Measurements

DECLINATION OBSERVATION

						VarD(nT)
WU:	18:19	204°	10'	12"	204.1700°	45.3
ED:	18:20	204°	05'	30"	204.0917°	45.3
WD:	18:21	024°	11'	30"	24.1917°	45.4
EU:	18:22	024°	05'	30"	24.0917°	45.4
Mean:	18:20	114°	08'	10"		
Declination:	18:20	003°	06'	39"	3.1108°	

INCLINATION OBSERVATION

						PPMF(nT)	VarH(nT)	VarZ(nT)
NU:	18:25	130°	14'	42"	-49.7550°	28470.0	-60.7	-17.1
SD:	18:26	310°	17'	00"	-49.7167°	28469.9	-60.6	-17.1
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SU:	18:28	049°	42'	00"	-49.7000°	28469.9	-60.7	-17.1
Inclination:	18:26	-049°	44'	11"	-49.7362°			

Observatory: BGS Test

Declination & Inclination Measurements

Results

BASELINES

	Absolute	GDAS	Baseline			
F (nT):	28438.4	28469.9	-31.5			
D(deg):	3.1108	0.1414	2.9695	002°	58'	10"
H (nT):	18380.0	-60.6	18440.6			
Z (nT):	-21700.7	-17.1	-21683.6			
I (deg):	-49.7362					

COLLIMATION ERRORS

Declination Delta: 000° 00' 20"

Declination Epsilon: 000° 00' -17"

Declination Zo (nT): -14.3

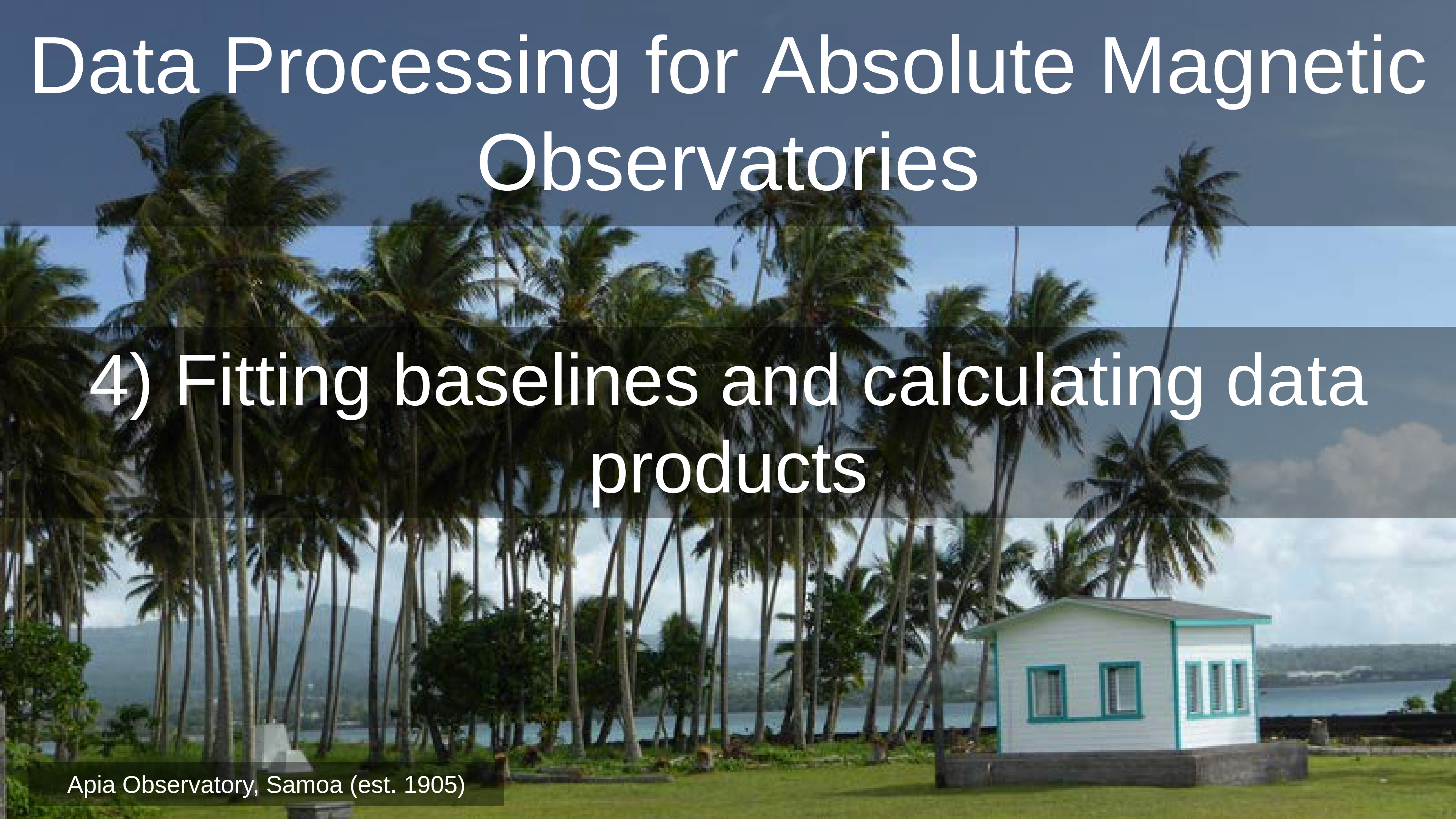
Inclination Epsilon: 000° 00' -02"

Inclination Zo (nT): -13.9

Inclination: 18:26 -049° 44' 11" -49.7362°

Data Processing for Absolute Magnetic Observatories

4) Fitting baselines and calculating data products



Apia Observatory, Samoa (est. 1905)

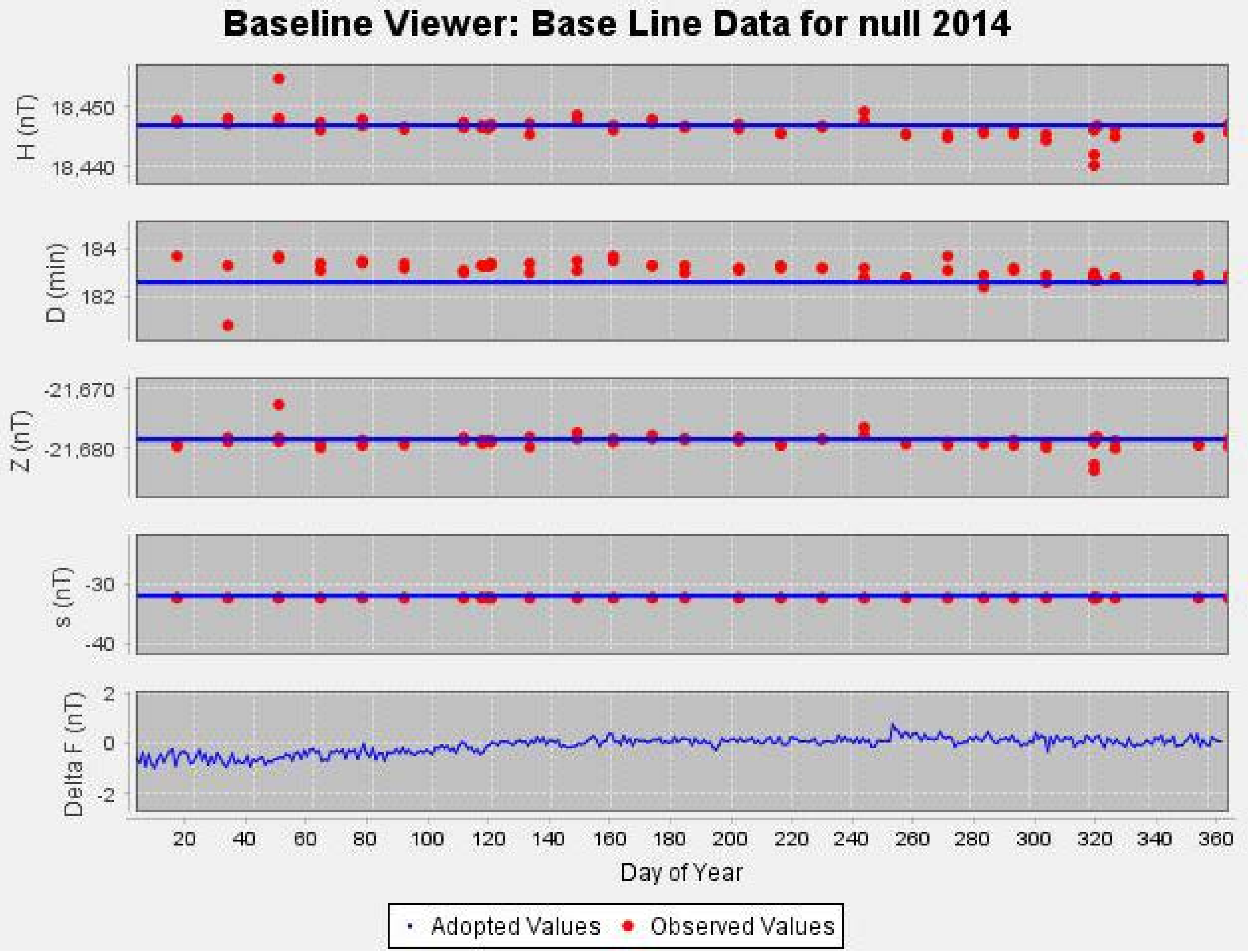
Instantaneous Baseline Record*

Date	Dec Time	Dec (deg)	Dbase (min)	Ddelta (deg)	Depsilon (deg)	DZ0 (nT)	Inc Time	Inc (deg)	Hbase (nT)	Zbase (nT)	Iepsilon (deg)	IZ0 (nT)	DIFlux	Mag	Observer	Site Diff
06-Feb-12	20:47:00	3.3665	220.5	0.0212	-0.0025	-13.62	20:56:00	-49.5579	18846.5	-21942.7	0.0063	-15.18	327865	886H	NB	-31.4
06-Feb-12	21:05:00	3.3652	220.5	0.0167	-0.0007	-15.65	20:29:00	-49.5563	18846.8	-21942.2	0.0013	-15.18	327865	886H	NB	-31.4
17-Feb-12	18:51:00	3.3854	220.4	0.0224	-0.007	-12.47	18:57:00	-49.5271	18846.2	-21943	0.0054	-12.69	327865	886H	NB	-31.4
17-Feb-12	19:05:00	3.3869	220.5	0.0258	-0.0078	-11.07	19:11:00	-49.5242	18846.9	-21942.3	0.0033	-12.9	327865	886H	NB	-31.4
04-Mar-12	13:01:00	3.2223	220.1	0.0154	-0.0018	-11.74	13:07:00	-49.5475	18846.5	-21943	0.0067	-13.58	327865	886H	NB	-31.4
04-Mar-12	13:15:00	3.2202	220	0.0167	-0.0028	-11.6	13:21:00	-49.55	18847.8	-21941.9	0.0042	-14.14	327865	886H	NB	-31.4

One observation per line including:

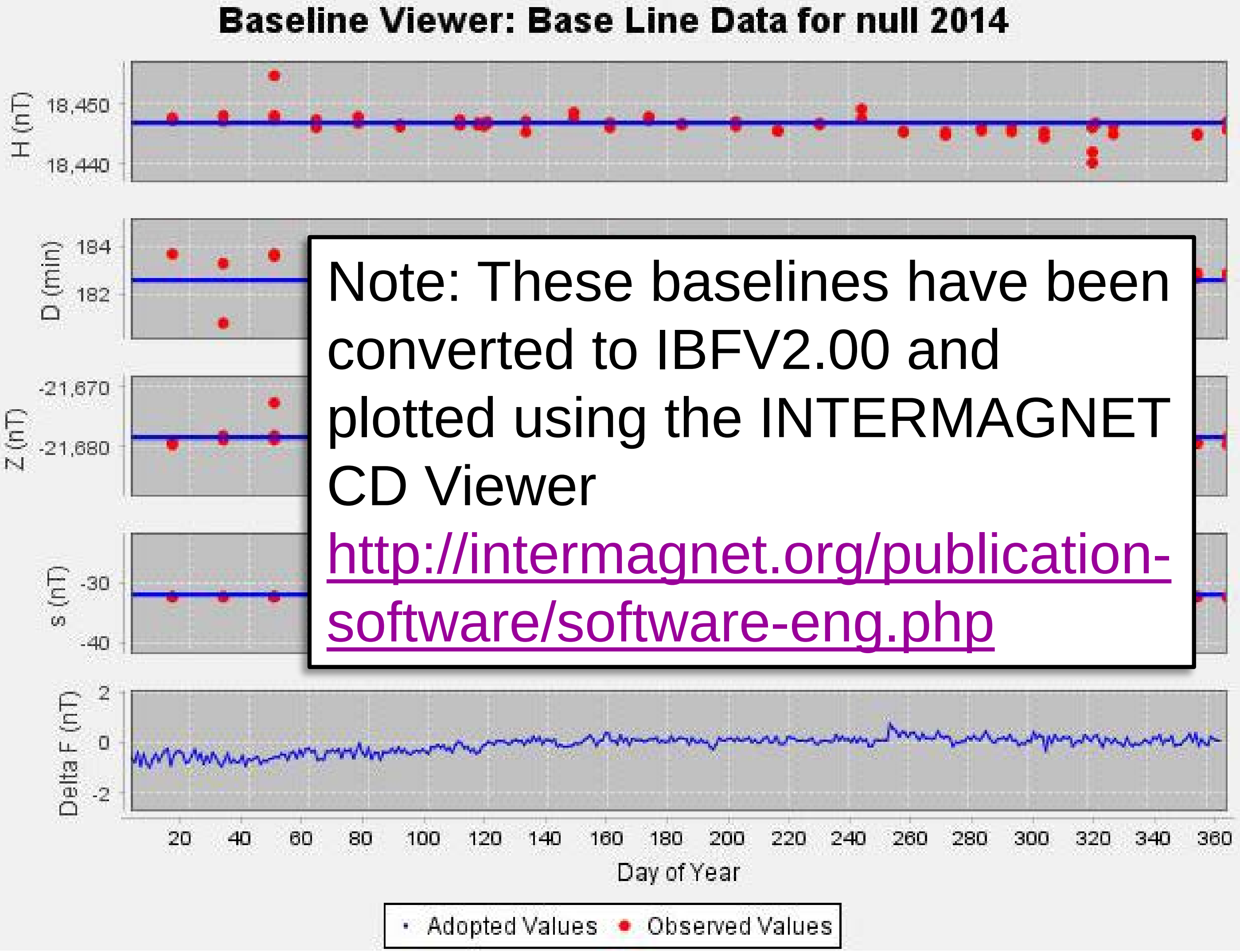
- Date & mean time of the declination and inclination observations
- Declination spot baseline
- H- and Z-component spot baselines
- Scalar site difference value
- Collimation angles and magnetometer offsets
- Instrument serial numbers
- Observer name

*this is a sample of a record used by BGS. Each observatory will have a different form of this record.



Modelling Baselines

This is a plot of spot baseline (red) over one year. To produce definitive data, these spot baselines must be modelled to produce a continuous, fitted baseline that can be applied to the variometer data. Here, the blue lines are a simple mean of all observations, which doesn’t model some of the instrument variations. There are also some outlier observations that need to be removed.



Note: These baselines have been converted to IBFV2.00 and plotted using the INTERMAGNET CD Viewer http://intermagnet.org/publication-software/software-eng.php

Modelling Baselines

This is a plot of spot baseline (red) over one year. To produce definitive data, these spot baselines must be modelled to produce a continuous, fitted baseline that can be applied to the variometer data.

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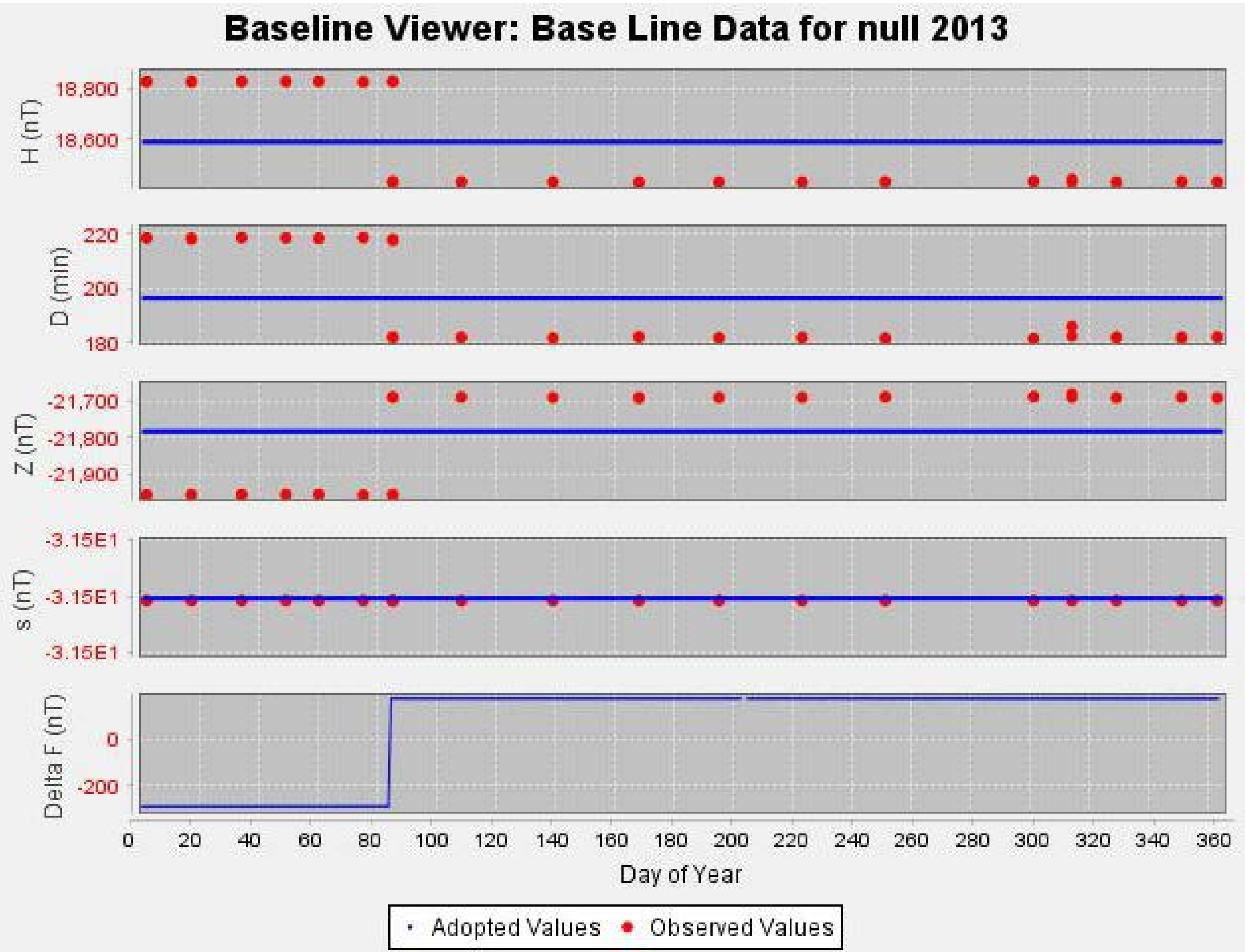
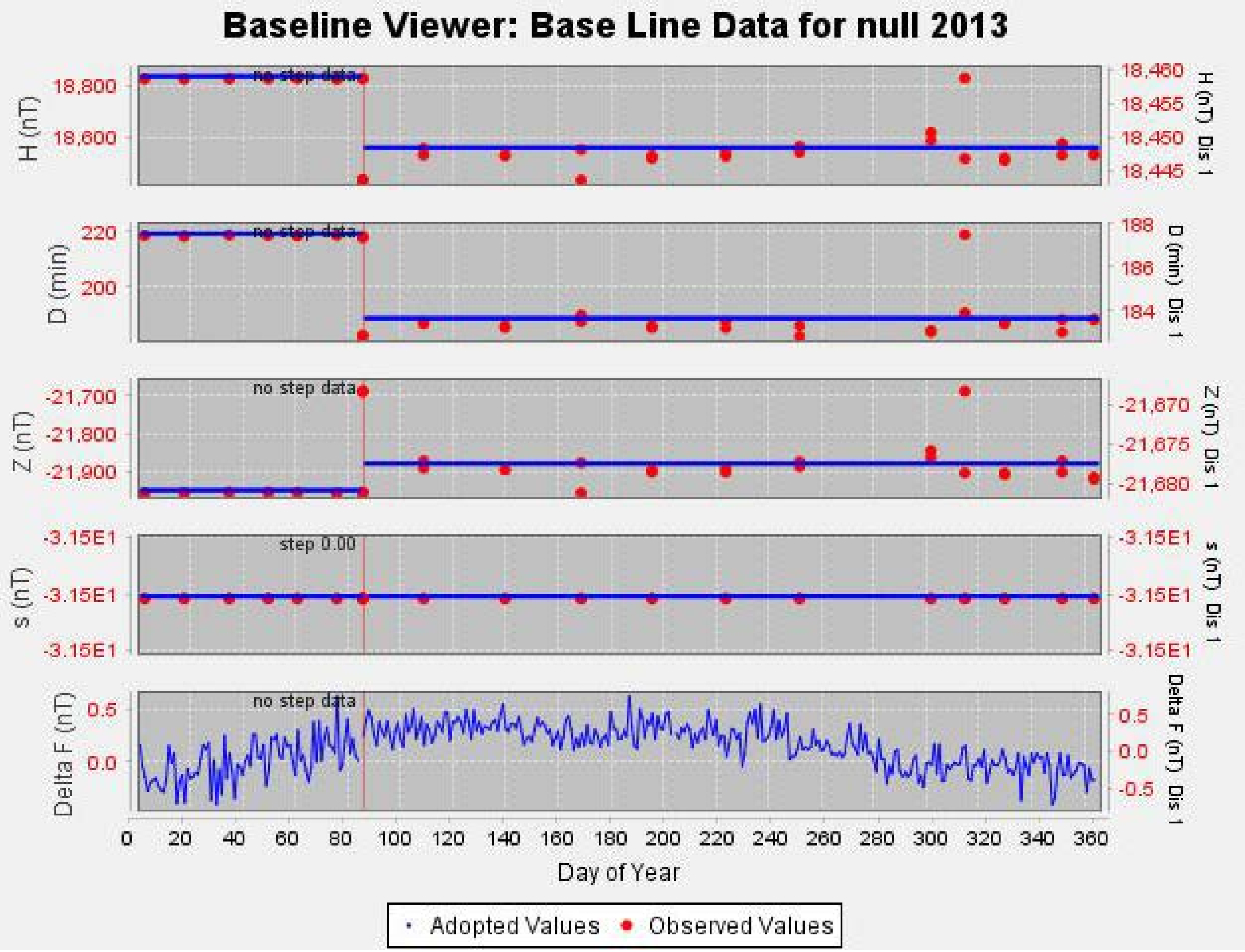


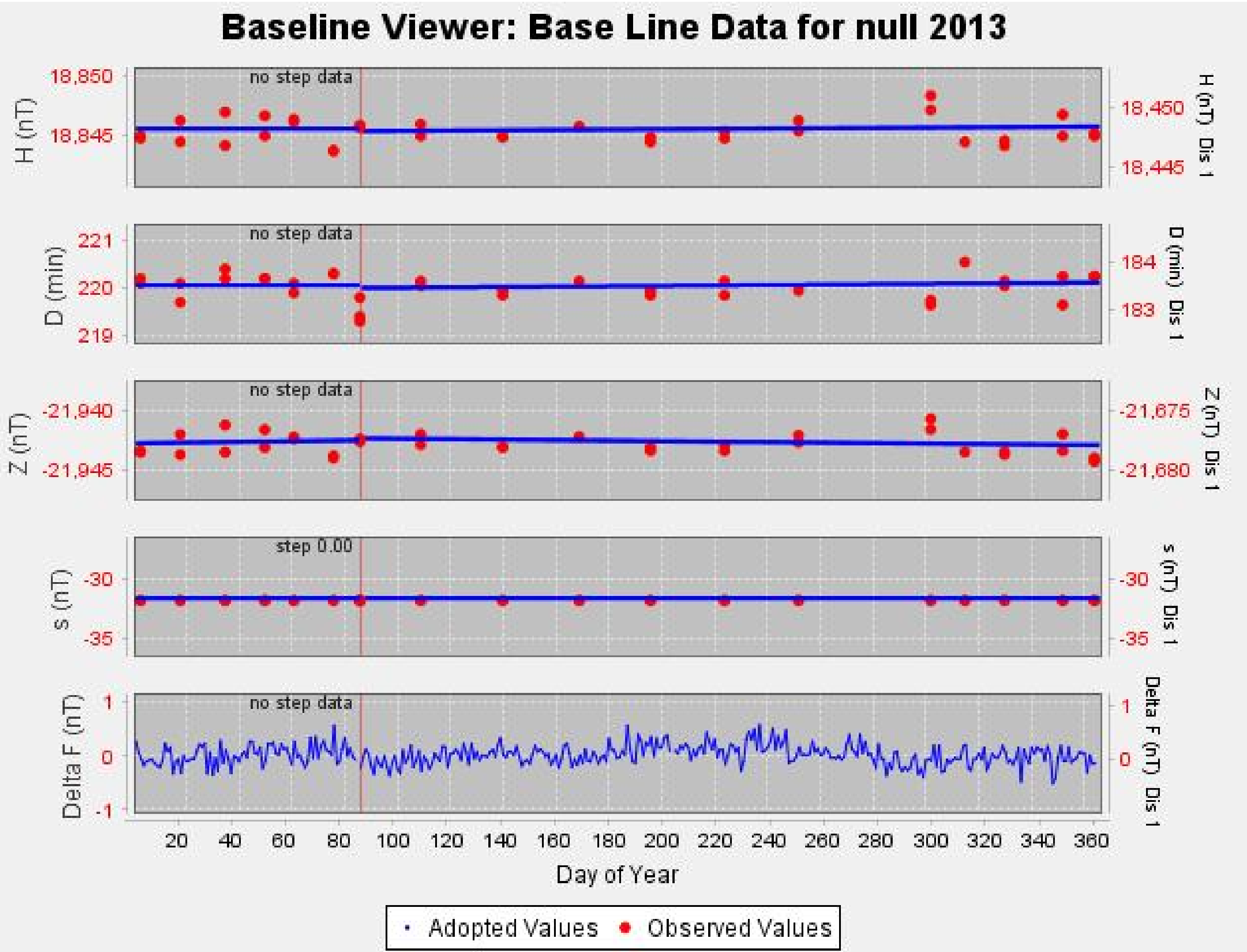
Modelling Baselines

This is a different year. There is a discontinuity on day 84 (25 March). The observatory diary lists that the variometer was re-aligned, so the baselines have to be modelled as two series, before and after the discontinuity.
Note that the, because the H- and Z-component baselines are poorly modelled, the resulting deltaF is also poor. This should be near zero.



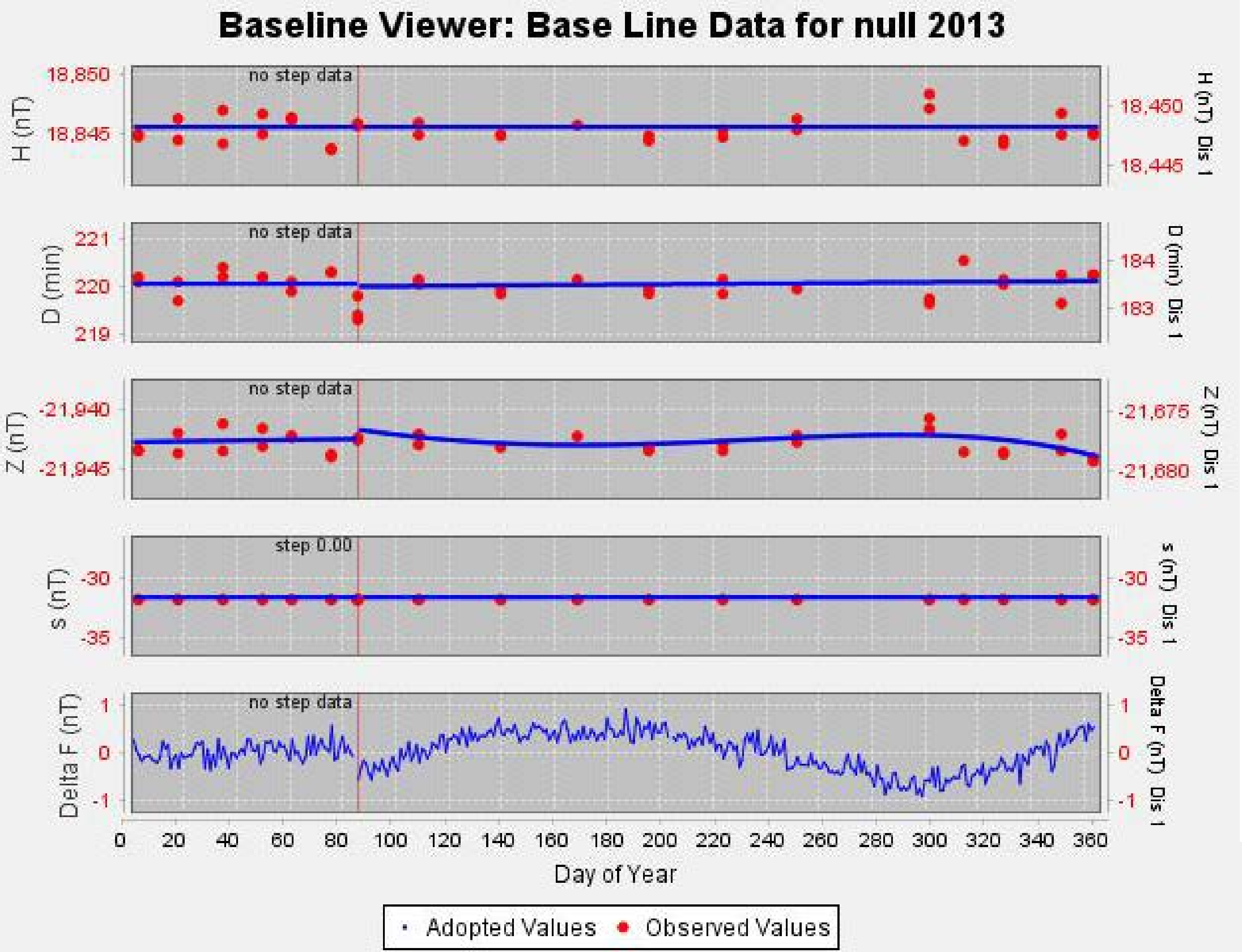
Modelling Baselines

Adding a discontinuity has improved the fit, including in deltaF. However, there are clearly outlying observations that need to be removed.
Also, the deltaF shows a trend in the instrument drift over the year that is not being modelled by a simple mean.



Modelling Baselines

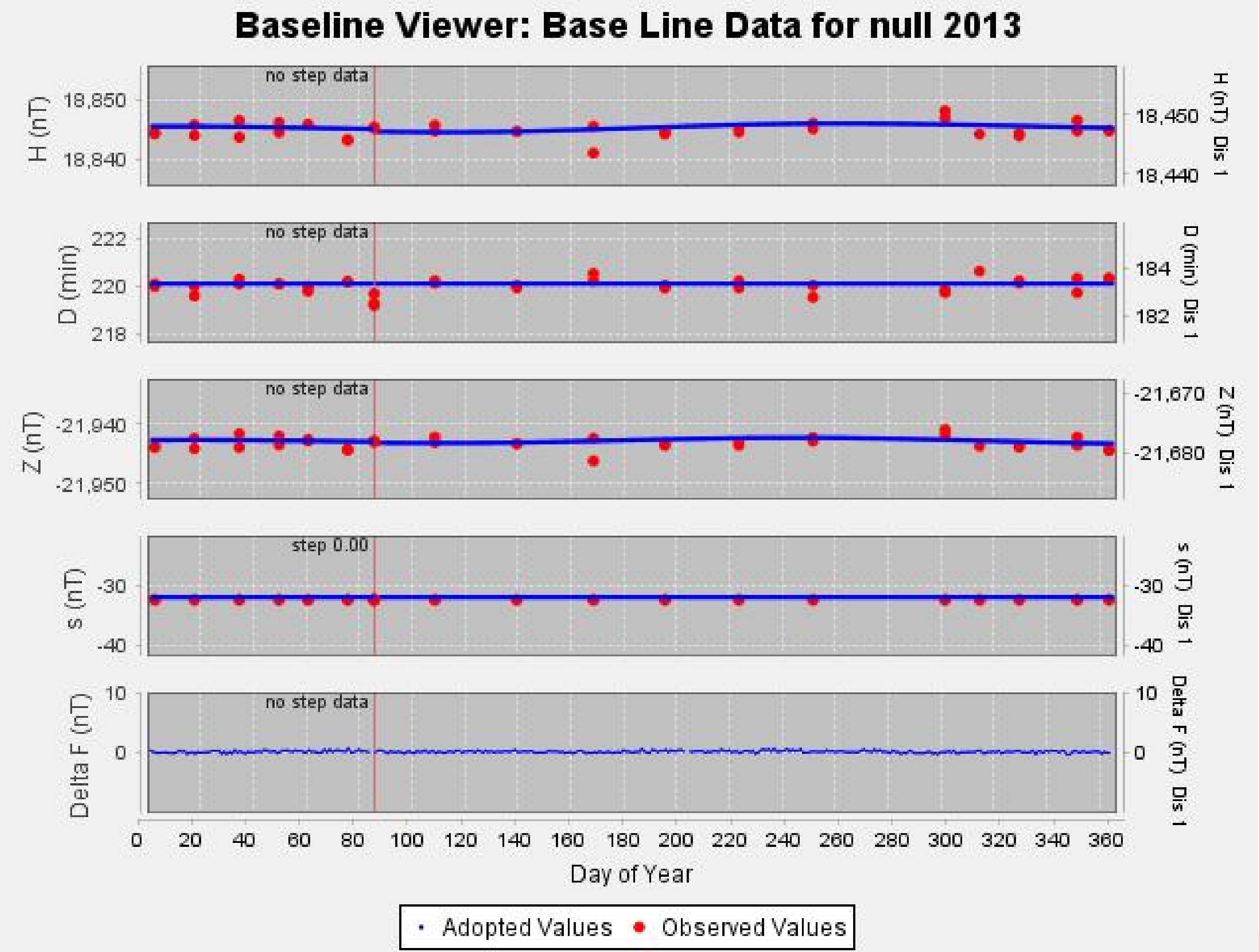
Removing the outliers and modelling the baselines either side of the discontinuity with an order 2 polynomial has further improved the fit, removing the trend in the deltaF. The range in deltaF over the year is now an acceptable 1nT. The baseline could perhaps be further improved by removing the outlying observations on day 300, however this would lead to a long gap, and hence uncertainty in the fitted baselines.



Modelling Baselines

Polynomials are easy to apply (e.g. using MS Excel) but they are often not representative of the variations in baseline, particularly high order polynomials, which can be influenced by outliers.

Here, the Z-baseline is modelled with a polynomial degree 5. The fit to the spot baselines is good, but the deltaF shows that this is over-fitted.



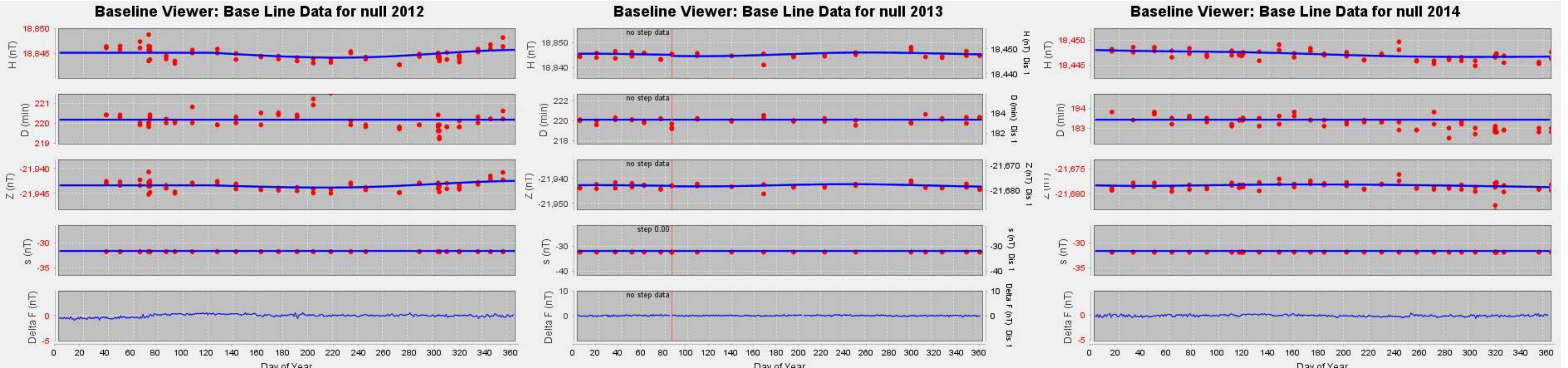
Modelling Baselines

A more realistic fit for observatory baselines is to use piece-wise, low-order polynomials i.e. fitting a number of consecutive polynomials of order ≤3, overlapping if possible to reduce the discontinuities at the intersections.

Taking this further, the fit here is using a uniform smoothing spline function (knot spacing 120 days). This fits a series of cubic polynomials whose gradients match at the knots (intersections)

Modelling Baselines

- Calculate baselines using variometer data rather than data with baselines added
- A number of modelling functions can be used to derive a fitted baseline, minimising residuals
- Identify discontinuities from the observatory diary and model before and after
- Absolute observations have errors. 3” reading resolution in inclination is 0.7nT at mid-latitude. Other errors include transcription errors, magnetic contamination, timing errors, instrument faults or calibration expiry, levelling errors, magnetic activity, problems at high or low latitudes
- To accurately model instrument drifts, variations between consecutive spot baselines should be ~1nT or less and gaps between observations should be less than two weeks
- Remove outliers if these are erroneous observations – look out for repeated errors e.g. same observer or instrument
- The objective is to realistically fit the spot baselines i.e. representative of the instrument drift
- Use hourly or daily means of deltaF to assess whether the fit is realistic or not
- Whichever method is used to model baselines, it is critical that the model includes sufficient observations in the previous year and the following year to ensure that the data are continuous over year boundaries



Guidance on Applying Baselines

- Maintain an observatory diary of instrument modifications, changes around the site, etc.
- Use daily magnetograms & comparisons to identify instrument problems at an early stage
- Perform frequent absolute observations
- Plot baseline plots after each observation to spot issues
- Maintain the magnetic cleanliness of the absolute pillar
- Maintain the variometer environment as stable as possible – temperature, humidity, magnetic contamination, etc. – and minimise changes
- Keep a temperature record of the variometer room temperature. Fluxgate magnetometer temperature dependencies can be ~1nT/ºC
- Regularly measure the scalar site difference

Novosibirsk Observatory, Russia

Producing Definitive Data

Definitive data are calculated using cleaned variometer data with final modelled baselines applied, preferably minute-by-minute

Data should be continuous including across year boundaries

Discontinuities are to be reported along with annual means and should be extrapolated to the year boundary. These are normally due to changes at the absolute pillar

Components of definitive data should be derived from one instrument such that components are consistent e.g. $F^2 = X^2+Y^2+Z^2$

Calculated means are all calculated from the base (e.g. one-minute) data

- Hourly: Minutes HH:00 to HH:59
- Daily: Minutes 00:00 to 23:59
- Monthly: Minute 00:00 on day one to 23:59 on final day
- Annual: Minute 00:00 on 1st January to 23:59 on 31st December

Means can be calculated if 90% or more data are available (IAGA resolution), otherwise mean data are flagged as missing

Metadata

```
                              BOU
             BOULDER OBSERVATORY INFORMATION 2008

ACKNOWLEDGEM: Users of the BOU data should acknowledge
              the U.S. Geological Survey

STATION ID  : BOU
LOCATION    : Boulder, Colorado, United States
ORGANIZATION: U.S. Geological Survey (USGS)
WEB-ADDRESS : http://geomag.usgs.gov
CO-LATITUDE :  49.86 Deg.
LONGITUDE   : 254.76 Deg. E
ELEVATION   : 1682 meters

ABSOLUTE
INSTRUMENTS : DI-fluxgate magnetometer (DI-flux) and an
              Overhauser type total field magnetometer
              (GEM Systems GSM 19-F)

RECORDING
VARIOMETER  : Three-component Narod ring-core fluxgate
              magnetometer.
ORIENTATION : HDZF
DYNAMIC RANGE:+/-80,000 nT
RESOLUTION:   0.01nT
SAMPLINGRATE: 1 sample per second
FILTER:        9-point Gaussian for 5-second values
              91-point Gaussian for 1-minute values


BACKUP
VARIOMETER:   None


K-NUMBERS:    USGS algorithm  mca-table method
K9-limit:     500 nT
```

Metadata are the associated information relevant to an observatory and its published data. Maintaining and publishing an accurate record of metadata is an important part of observatory practice and is essential for future reference.

Observatory metadata includes:

- Observatory latitude, longitude and elevation
- Contact details
- Instruments and filtering
- Data processing details
- Observatory changes and amendments to previous data

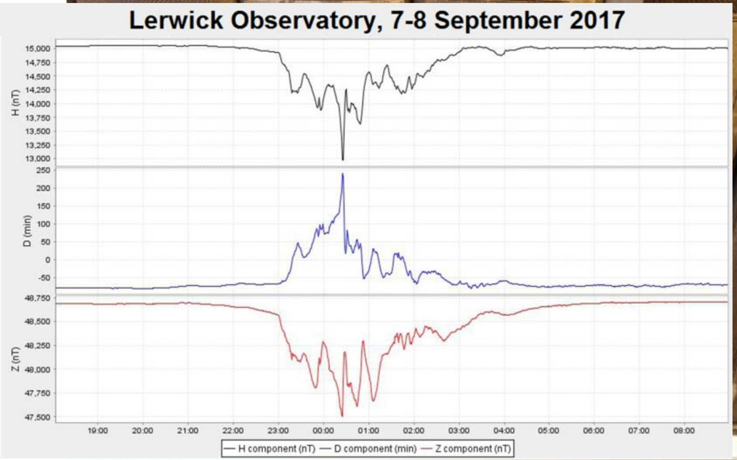
Why do we need metadata?

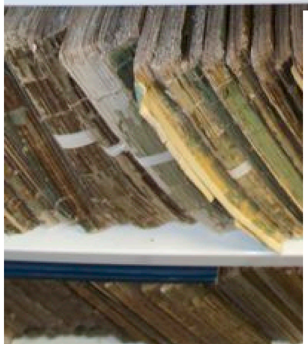
Metadata is the vital information around the data that informs what the data are and how they were produced.

This information needs to be preserved for the future, but metadata is not being recorded as it was when yearbooks were produced by observatories

Digital exchange of data is easy today but as data are transferred and reformatted, metadata is regularly lost

There is a need for a common metadata protocol in the same way as common data formats allow data to be readily preserved, exchanged and interpreted





Working towards a Metadata standard for geomagnetic observatories

Primary driver:

- Funded by the European Horizon 2020 project EPOS (European Plate Observing System)
- Peer reviewed by the geomagnetic observatory community
- Peer reviewed by database experts

Implementation:

- A set of tables in a relational database
    - (About 30 tables and 15 dictionaries)
- Hosted on BGS ORACLE servers
- All text can be held in multiple languages (“internationalised”)
- All entities (addresses, personnel, instruments, etc.) have validity dates

SEISMOLOGY | NEAR FAULT OBSERVATORIES | GNSS DATA AND PRODUCTS | VOLCANO OBSERVATIONS | SATELLITE DATA | GEOMAGNETIC OBSERVATIONS | ANTHROPOGENIC HAZARDS | GEOLOGICAL INFORMATION AND MODELING | MULTI-SCALE LABORATORIES | GEO-ENERGY TEST BEDS FOR LOW CARBON ENERGY

EPOS
EUROPEANPLATEOBSERVINGSYSTEM

Working towards a Metadata standard for geomagnetic observatories

Primary driver:

- Funded by t … te Observing System)
- Peer review
- Peer review

Implementation

- A set of tab
  - (About
- Hosted on E
- All text can
- All entities (… es

To do:

- Finish the work to supply INTERMAGNET website metadata
- Creation of Digital Object Identifiers for INTERMAGNET
- Filling of metadata from existing sources (hard work because much of the metadata is not structured):
  - INTERMAGNET CD-ROMs and DVD
  - World Data Centres

SEISMOLOGY | NEAR FAULT OBSERVATORIES | GNSS DATA AND PRODUCTS | VOLCANO OBSERVATIONS | SATELLITE DATA | GEOMAGNETIC OBSERVATIONS | ANTHROPOGENIC HAZARDS | GEOLOGICAL INFORMATION AND MODELING | MULTI-SCALE LABORATORIES | GEO-ENERGY TEST BEDS FOR LOW CARBON ENERGY

EPOS EUROPEAN PLATE OBSERVING SYSTEM

Data Processing for Absolute Magnetic Observatories

5) Publishing data: World Data Centre & INTERMAGNET

Apia Observatory, Samoa (est. 1905)

World Data Centres for Geomagnetism

Mirrored sites:

World Data Centre for Geomagnetism, Kyoto
http://swdcwww.kugi.kyoto-u.ac.jp/catmap/index.html
World Data Centre for Geomagnetism, Edinburgh
http://www.wdc.bgs.ac.uk/

Non-mirrored/regional sites:

World Data Centre (WDC) for Geomagnetism, Mumbai
http://wdciig.res.in/WebUI/Home.aspx
World Data Centre for Solid Earth Physics (Geomagnetism)
http://www.wdcb.ru/sep/magnetic_measurements/magnetic_measurements.html

WDC | Geomagnetism Edinburgh

Home Data About Usage Rules Contact

World Data Centre for Geomagnetism, Edinburgh

See our data »

About

Find out more about the WDC for Geomagnetism, Edinburgh.

View details »

Usage Rules

Find out how these data can be used and by who.

View details »

Contact

We want your data! Find out how to submit datasets, or ask a question about our holdings.

View details »

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Operated by the British Geological Survey.

ICSU WORLD DATA SYSTEM

A Regular Member of the World Data System.

WDC | Geomagnetism Edinburgh

Home Data About Usage Rules Contact

World Data Centre for

Catalogue holdings:

- One-minute means definitive data
- Definitive means: Hourly, Annual
- Magnetic survey data (land & marine)
- Observatory Yearbooks

Geomagnetism, Edinburgh.

View details »

who.

View details »

datasets, or ask a question about our holdings.

View details »

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WDC | Geomagnetism Edinburgh

Home Data About Usage Rules Contact

World Data Centre for

Submitting data:

- Digital data in various time cadences, survey data, yearbooks, etc:
- FTP upload for digital data
- Annual call for data Feb/Mar using WDC Edinburgh mailing list
- Contact: wdcgeomag@bgs.ac.uk

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Operated by the British Geological Survey.

ICSU WORLD DATA SYSTEM

A Regular Member of the World Data System.

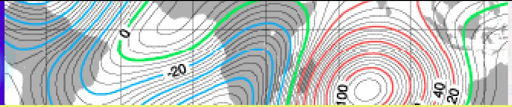
Definitive one-minute & hourly means:

- Preferred data formats: IAGA-2002 or IAFV2.1 (INTERMAGNET binary)
- Checks: Visual scan; compared with nearby (<500km) observatory if available using IMCDView; check with global model to identify year boundary steps

Annual means:

- Manual entry, so any ASCII format is acceptable. Non-submitted components will be calculated
- Can accept partial year, if submitted with an epoch
- Steps should be noted and applied at the year boundary. Catalogue contains note of step size with description
- Significant site moves (tens km) are recorded as a new observatory code
- Checks: internal consistency between components and continuity plot

IAGA Division V-MOD
Geomagnetic Field Modeling



How are the data in the WDC used?

IUGG > IAGA > Division V > Working Group V-MOD > IGRF Model

International Geomagnetic Reference Field

IGRF-12 is released. Download the latest IGRF model here : IGRF-12 coefficients (text file, excel spreadsheet)

Fortran program with IGRF-12 coefficients integrated into the source code, provided by BGS.

IGRF12 online calculators: (NGDC IGRF-12 Calculator!) (BGS IGRF-12 Calculator!)

Geomag 7.0 C software and model is released! The updated igrf12.cof required by many users is now available along with the new Geomag 7.0 software. (Windows version, Linux tar file). License and copyright information for the geomag 7.0 software.

The International Association of Geomagnetism and Aeronomy (IAGA) has released the 12 th Generation International Geomagnetic Reference Field — the latest version of a standard mathematical description of the Earth's main magnetic field that is used widely in studies of the Earth's deep interior, its crust and its ionosphere and magnetosphere. The coefficients for this degree and order 13 main field model were finalized by a task force of IAGA in December 2014. The IGRF is the product of a collaborative effort between magnetic field modellers and the institutes involved in collecting and disseminating magnetic field data from satellites and from observatories and surveys around the world.

The IGRF is a series of mathematical models of the Earth's main field and its annual rate of change (secular variation). In source-free regions at the Earth's surface and above, the main field, with sources internal to the Earth, is the negative gradient of a scalar potential *V* which can be represented by a truncated series expansion:

$$V(r,\theta,\phi,t) = a \sum_{n=1}^{N} \sum_{m=0}^{n} \left(\frac{a}{r}\right)^{n+1} \left[g_n^m(t)\cos(m\phi) + h_n^m(t)\sin(m\phi)\right] P_n^m(\cos\theta)$$

Here, a = 6371.2 km and the degree of truncation is N = 13. The 12 th Generation IGRF coefficients were computed from candidate sets of coefficients produced by the participating members of IAGA Working Group V-MOD. Their institutes and the many organisations involved in operating magnetic survey satellites, observatories, magnetic survey programmes and World Data Centers are to be thanked for their continuing support of the IGRF project.

Before using the IGRF please look at the "Health Warning".

Please refer to:

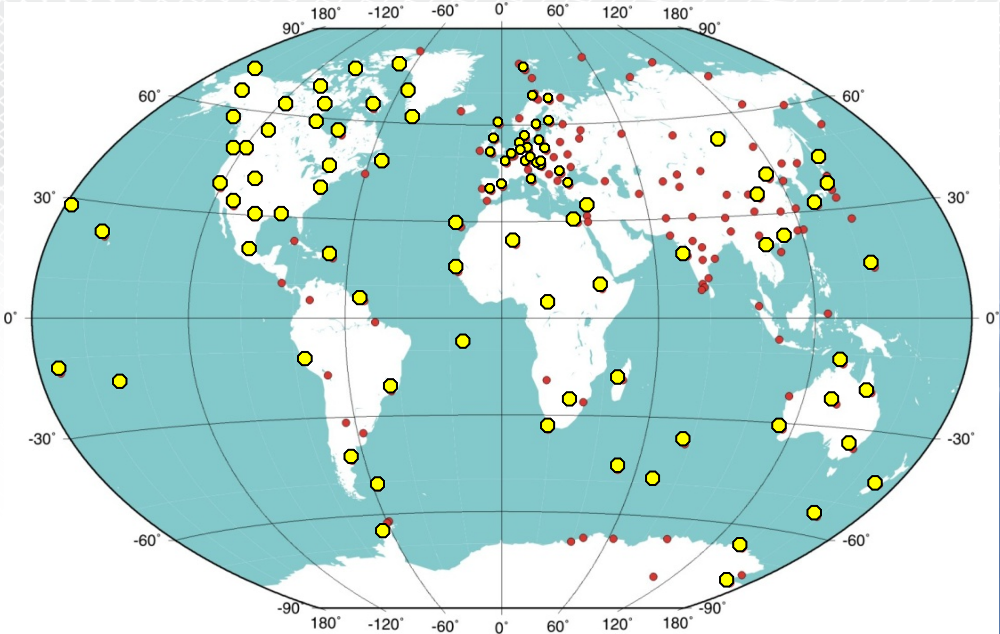
International Geomagnetic Reference Field: the 12th generation, Erwan Thébault, Christopher C Finlay, Ciarán D Beggan, Patrick Alken, Julien Aubert, Olivier Barrois,

INTERMAGNET

Real-time world-wide magnetic observatory data

“The INTERMAGNET objective is to establish a global network of cooperating digital magnetic observatories, adopting modern standard specifications for measuring and recording equipment, in order to facilitate data exchange and the production of geomagnetic products in close to real time.”

- Formed by IAGA resolution following a data transmission pilot in 1989
- Data exchange & publication for non-commercial benefit
- Specified minimum data quality standard
- Over 20 years of high quality data available for research



www.intermagnet.org

INTERMAGNET Membership Conditions

- **Transmission of reported (raw) one-minute data within 72 hours to INTERMAGNET GIN**
- **Submission of one-minute definitive data at the end of each calendar year, meeting data quality specifications:**
  - Absolute accuracy: ±5 nT
  - Resolution: 0.1 nT
  - Band pass: D.C. to 0.1 Hz
  - Inclusion of metadata; instrument baseline file, annual means file, observatory readme file
- **Use of INTERMAGNET data exchange formats**
- **Full specifications documented in the INTERMAGNET Technical Manual**

INTERMAGNET
Making an Application

- Ensure data operations, data quality and data formatting comply:

  http://intermagnet.org/publication-software/technicalsoft-eng.php

- Prepare definitive data and metadata:
  - Twelve consecutive months of definitive one-minute mean data in INTERMAGNET format IAFV2.1 (XYZ)
  - INTERMAGNET baseline files for the same period in INTERMAGNET format IBFV2.00
  - An annual mean file in INTERMAGNET format IYFV1.01
  - Readme file (country and observatory)
- Use of INTERMAGNET data exchange formats:

  http://intermagnet.org/data-donnee/formatdata-eng.php

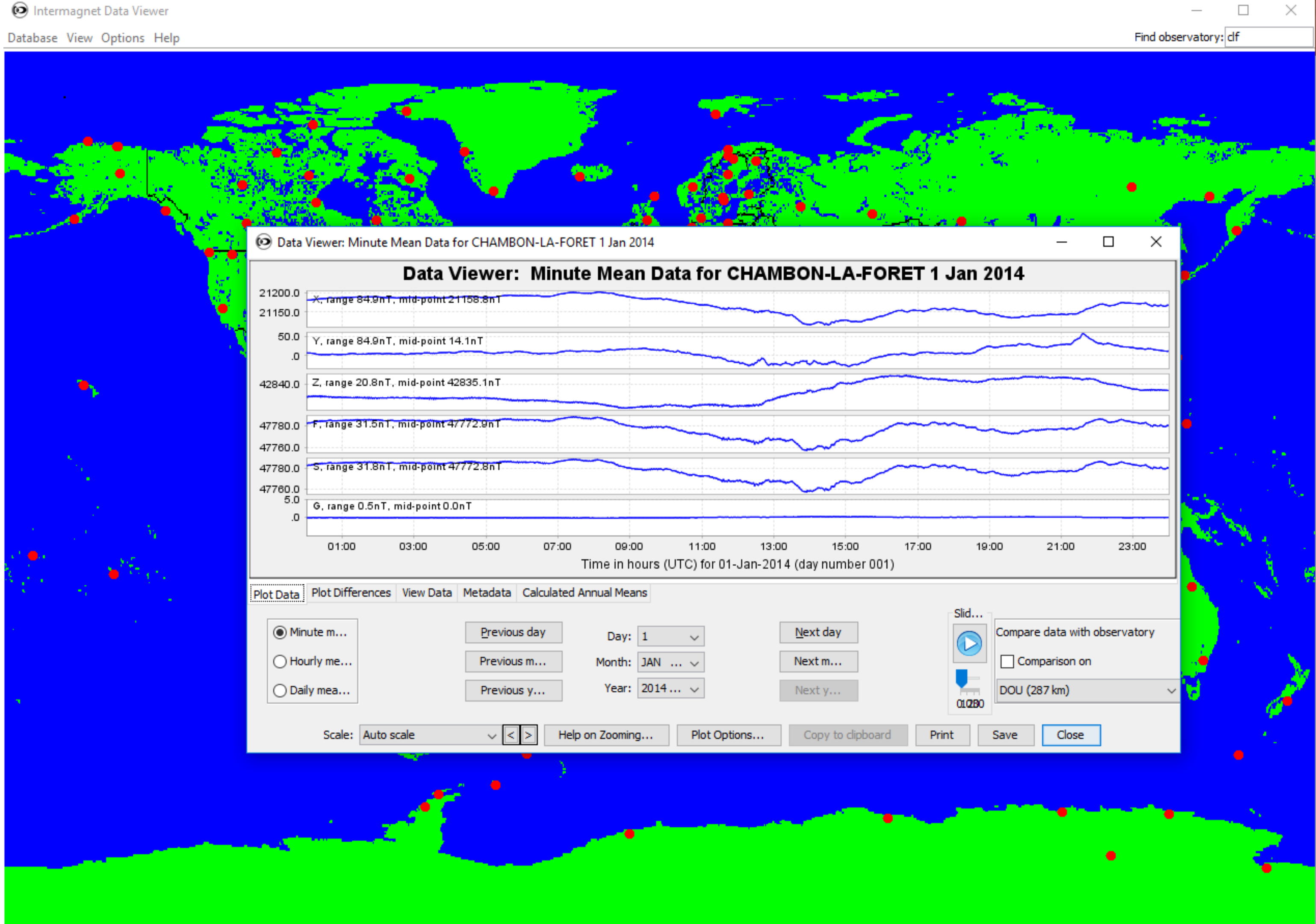
- Complete an INTERMAGNET observatory application form and send to IMO Subcommittee chair:

  http://intermagnet.org/imos/apply-eng.php

INTERMAGNET
Definitive data Submission Notes

- Definitive data are uploaded to the FTP site of the Paris GIN ftp://par-gin.ipgp.fr (password required)
- INTERMAGNET Observatories (IMO) are asked to submit one-minute data in XYZG
- When the data are checked by INTERMAGNET, part of the process is an assessment using the DOS program **check1min.exe**. This is available from the Paris GIN FTP site and is self-explanatory when you execute it so you can easily run these checks yourself. This software checks:
  - File formats
  - Consistency of metadata across all files
  - Correct mean values calculations
  - Consistency of components in annual mean files e.g. $F^2 = X^2+Y^2+Z^2$
- Data checkers also use IMCDView application to inspect data for continuity, noise, baseline quality and to compare with other observatories

INTERMAGNET
IMCDView Data Viewer



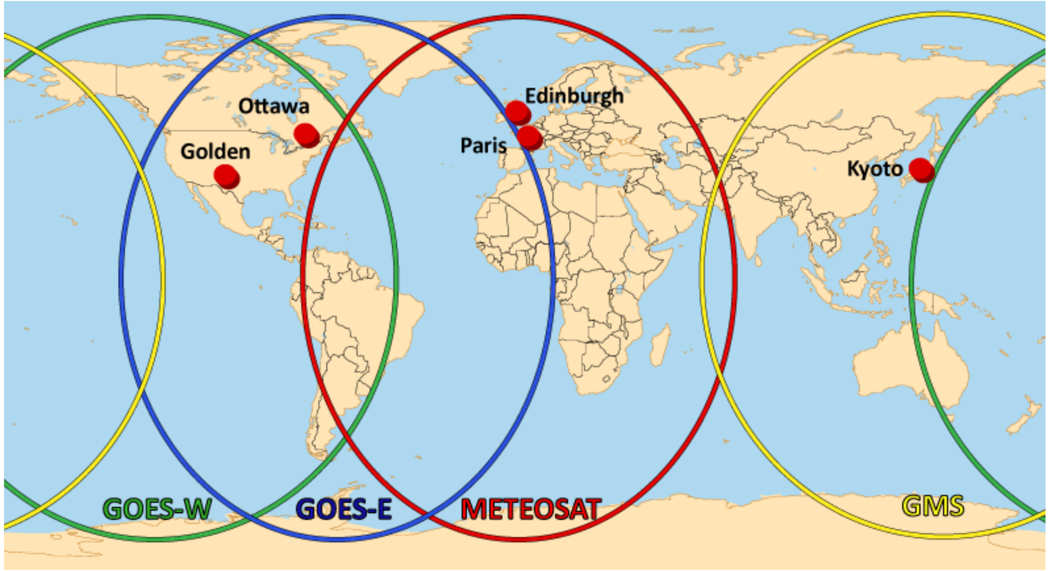
INTERMAGNET IMCDView Data Viewer

- Download IMCDView Java JAR file from:
- http://intermagnet.org/publication-software/software-eng.php
- Used for reading, plotting and extracting data from INTERMAGNET format files
- i.e. INTERMAGNET binary files, baseline files, annual mean files and readme files
- Can be used to generate INTERMAGNET binary files from IAGA-2002 files but is to be superseded
- New INTERMAGNET file format conversion utility*: ftp://ftp.nmh.ac.uk/INTERMAGNET/software/gm_convert/

*note this is currently a beta version

INTERMAGNET
Geomagnetic Information Nodes

“GINs are are the collection points for real-time data within INTERMAGNET. They are connected to the INTERMAGNET observatories by satellite, computer and telephone networks. Minute mean observations of the earth's magnetic field are relayed to the GINs within 72 hours of recording. This time is substantially reduced when observatories are using satellite communications.”



These days, GINs are used to send reported, adjusted and quasi-definitive data to INTERMAGNET either by e-mail or web transfer.

Data Processing for Absolute Magnetic Observatories

6) Other data products: QD, indices and one-second data

Apia Observatory, Samoa (est. 1905)

INTERMAGNET
Quasi-definitive Data

What is quasi-definitive data? http://intermagnet.org/faqs-eng.php#quasi-definitive

INTERMAGNET has defined a standard for a data type called quasi-definitive. As the name implies, the data should be close to the expected definitive value, but is to be delivered more rapidly than an observatory's annual definitive data. This initiative will be useful for a number of scientific activities, where timely and close-to-definitive data is essential. For example, quasi-definitive data will be particularly useful in joint analyses of geomagnetic and other phenomena, together with data measured by satellites. Quasi-definitive data are 1-minute or 1-second data (observatories are encouraged to produce both minute and second data) that can be submitted to INTERMAGNET as (H, D, Z) or (X, Y, Z) and have the following properties:

Corrected using temporary baselines

Made available less than 3 months after their acquisition

Such that the difference between the quasi-definitive and definitive (X, Y, Z) monthly means is less than 5 nT in any component for every month of the year

Point c is checked a posteriori by comparing quasi-definitive and definitive data from the previous year.

INTERMAGNET
Quasi-definitive Data

What is quasi-definitive data? http://intermagnet.org/faqs-eng.php#quasi-definitive

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(H, D, Z) or (X, …

Corrected using …

Made available …

Such that the d … onthly means is less
than 5 nT in an …

Point c is checked a posteriori by comparing quasi-definitive and definitive data from the previous year.

Observatories are strongly encouraged to submit quasi-definitive data that is thoroughly controlled, i.e. de-spiked, free from corrupted data, data gaps filled in from back-up systems, and with the best possible baseline at the time of submission. Submission of quasi-definitive data should not be seen as having satisfied the requirements for definitive data. The annual definitive data, again thoroughly controlled and with a baseline based on a full year of absolute measurements, shall be submitted in the formats for definitive data at latest by the deadline agreed by INTERMAGNET.

INTERMAGNET
One Second Definitive Data

General Specifications	
Time-stamp accuracy	0.01 s
Phase response	±0.01 s
Maximum filter width	25 seconds
Instrument Amplitude Range	≥±4000 nT High Latitude, ≥±3000 nT Mid/Equatorial Latitude
Data resolution	1 pT
Pass band	DC to 0.2 Hz
Maximum component orthogonality error	2 mrad
Maximum Z-component verticality error	2 mrad
Pass Band Specifications [DC to 8 mHz (120 s)]	
Noise level	≤100 pT RMS
Maximum offset error	±2. 5 nT
Maximum component scaling & linearity error	0.25%
Pass Band Specifications [8 mHz (120 s) to 0.2 Hz]	
Noise level	≤10 pT/√Hz at 0.1 Hz
Maximum gain/attenuation	3 dB
Stop Band Specifications [≥ 0.5 Hz]	
Minimum attenuation in the stop band (≥ 0.5Hz)	50 dB
Auxiliary measurements:	

Compulsory full-scale scalar magnetometer measurements with a data resolution of 0.01 nT at a minimum sample period of 30 seconds.

Kp	NOAA G-scales	
	Category	Description
<3+		
3+		
4-		
4o		
4+		
5-	G1	Kp = 5
5o		
5+		
6-	G2	Kp = 6
6o		
6+		
7-	G3	Kp = 7
7o		
7+		
8-	G4	Kp = 8
8o		
8+		
9-		
9o	G5	Kp = 9

Geomagnetic Indices

Geomagnetic indices are used to represent characteristics of the magnetic field and are useful to researchers and industry in parameterising field variations or the processes that cause them. A list of IAGA indices is given by ISGI:

http://isgi.unistra.fr/geomagnetic_indices.php

The *K*-index is a commonly used proxy for external field activity. This quasi-logarithmic scale is produced by each observatory using a *K*=9 lower limit specific to that observatory. A planetary *Kp*-index is maintained by GFZ Potsdam

https://www.gfz-potsdam.de/kp-index/

Observatories can obtain a value for the *K*=9 lower limit from ISGS and can use utilities such as KASM to compute *K* from definitive data e.g. inputting from and outputting to INTERMAGNET binary (IAFV2.1) files.

http://magneto.igf.edu.pl/soft/kasm/