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Reporter Review: Recent improvements to geomagnetic observatory practice, instrumentation and global network

By

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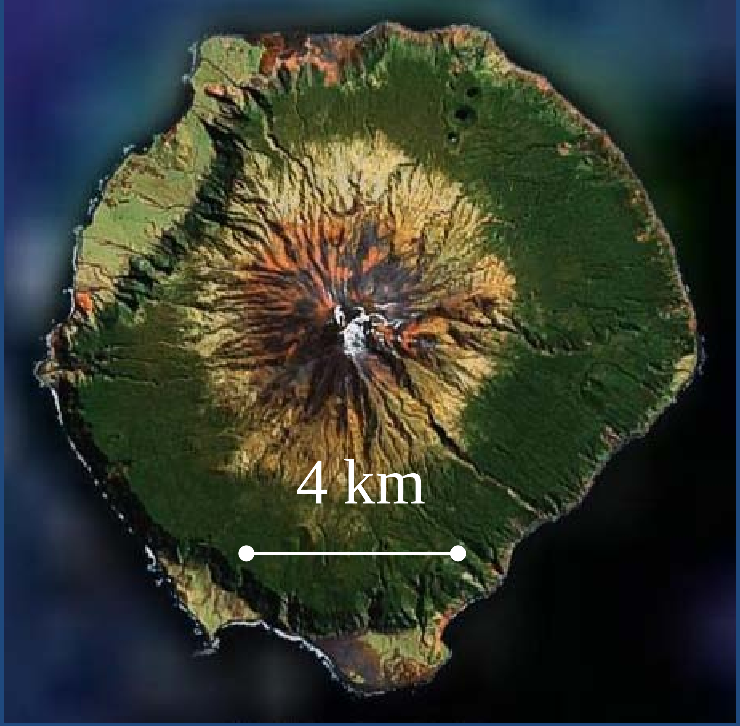
Outline

- Improvements to the global network
  - New observatories
  - Remote locations
- Instrumentation
  - Absolute directional measurements
  - Automatic DI Flux designs
  - New magnetometers
- Noise reduction / identification in observatory data
- Challenges using 1 sec data (Indices)
- Modelling on regional scale

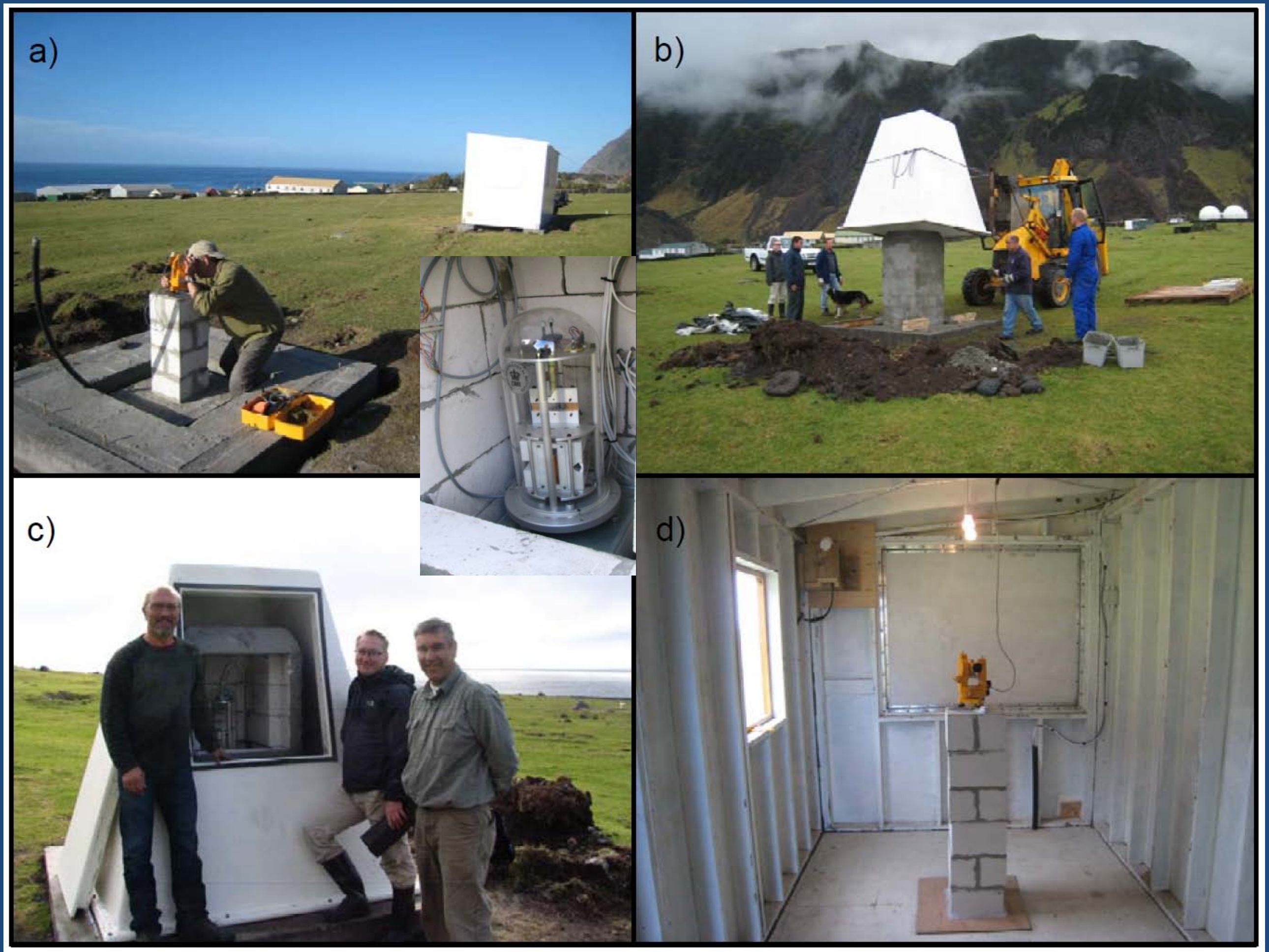
New Observatories

- Tristan de Cunha: TDC (started 01-10-2009)
- Dome C in Antarctica: DMC (started 2005, but continuous since 01-01-2009)
- Cheongyang-Gun, Korea: CYG (started 04-2009)
- Dalat, Vietnam: DLT (started 20-04-2010)
- Deadhorse, Alaska: DED (new)
- King Edward Point, South Georgia Island: KEP (started 01-03-2011)


4 km


Tristan da Cunha
37 S, 12 W

Tristan de Cunha: TDC
(Buildings to house instruments)



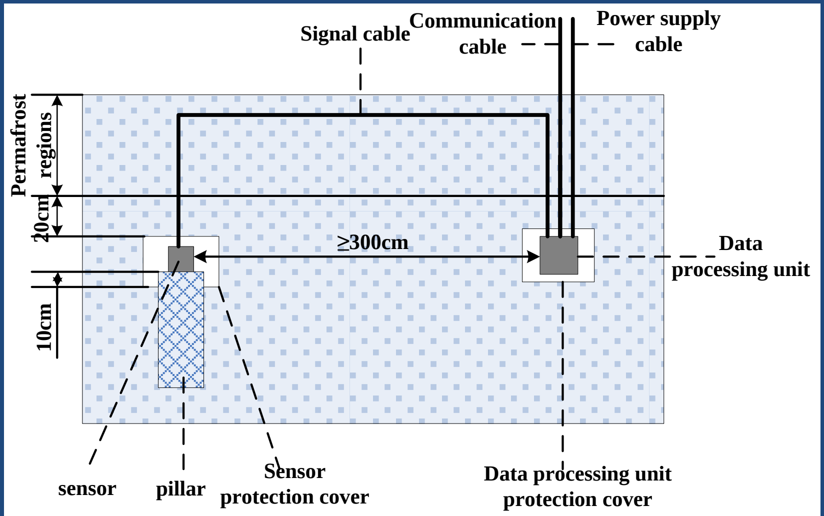
Despite the remoteness and volcanic nature of Tristan da Cunha, the geomagnetic observatory delivers data with good baselines. There were several occasions in 2010 with data gaps of a few days.

‘Coffin-type’ Observatories

CLF

KMH

Schematic layout



CONRAD Observatory: A unique and multi – disciplinary facility

1. Located inside Austrian Alps to accommodate both magnetic and seismic instruments
2. 150 m long tunnels for temperature control
3. 50-100 m deep vertical shafts: several potassium and other magnetometers

Real-Time Monitoring of Pillar Differences

- Overhauser GSM 90 Model
- Approx. 1.5 m above pillar
- 5 sec data -> 1 min data

- DI Flux: Zeiss 010 B

Absolute Directional Observations

- Still the ‘heart and soul’ of any observatory
- Determines the ultimate quality of data

  - DI3: 3-axis magnetometer & theodolite

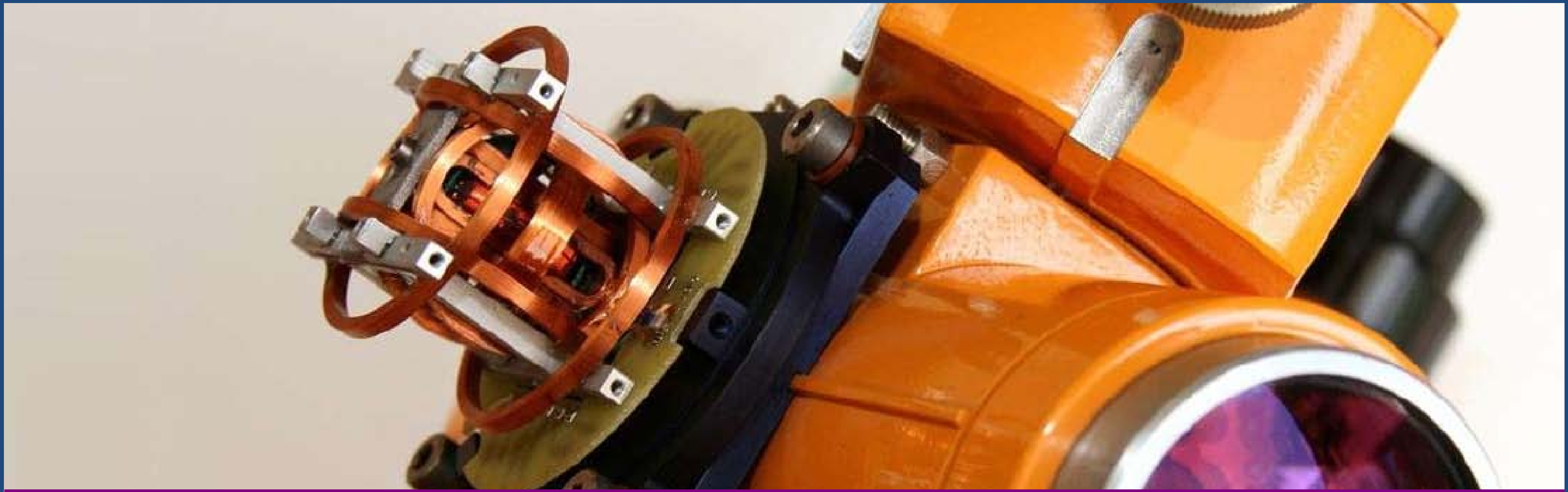
  - Automatic measurements

    GAUSS

    AUTODIF

Technische Universität Braunschweig

GFZ Potsdam Helmholtz Association

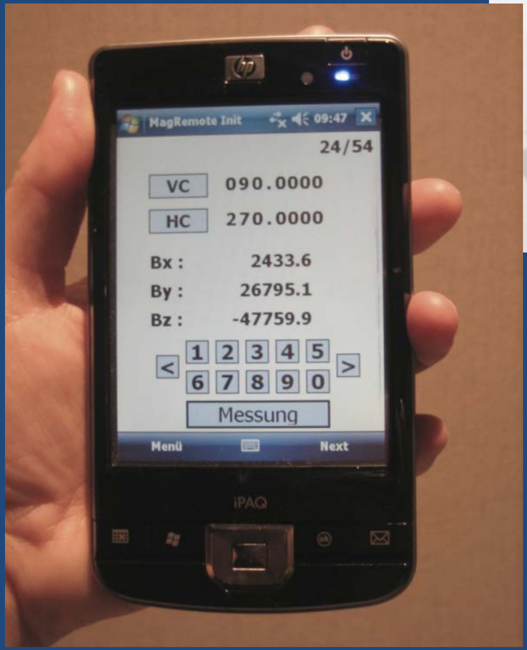


DI3 – A new Procedure for Absolute Directional Measurements

Components

- Zeiss Theodolite (010B)
- Vector compensated fluxgate magnetometer (Magson / TU-BS)
    - Full Earth field range with non linearity less than $2 * 10^{-5}$
    - Resolution 0.1nT
    - Flown on various ESA and NASA space missions

- PDA connected with magnetometer via Bluetooth interface

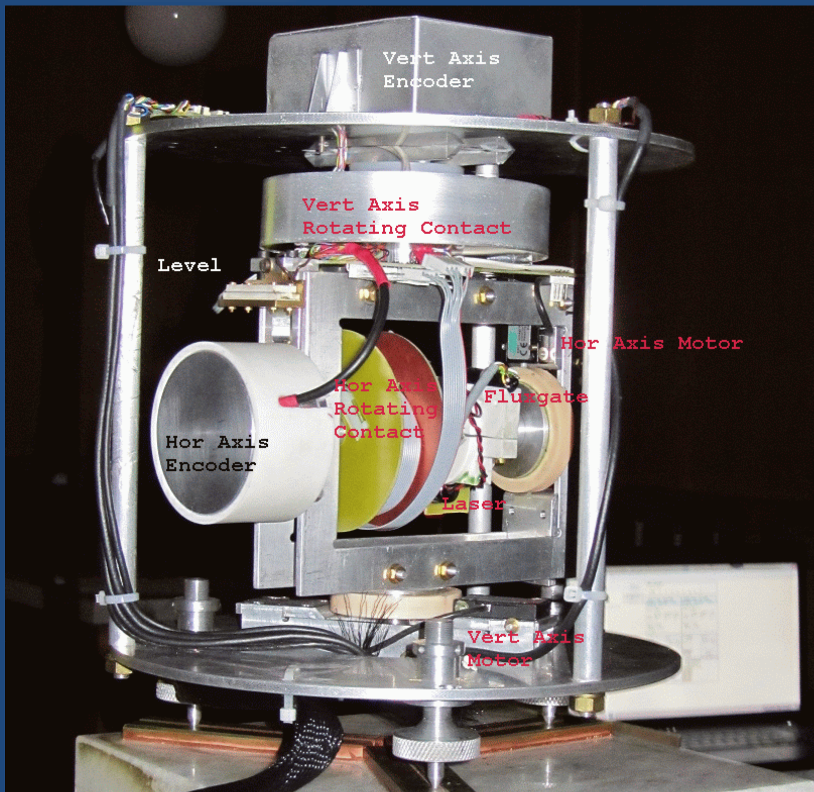


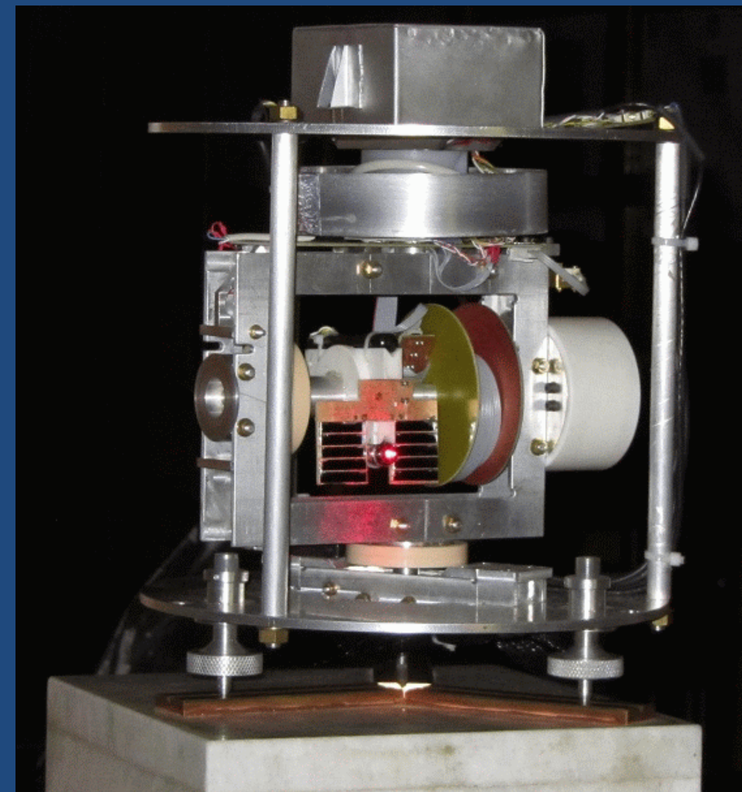
Advantages

- 1: The usage of the 3D magnetometer allows the determination of an error bar for an absolute measurement for the first time

- 2: The usage of the 3D magnetometer on the theodolite improves the reliability of the absolute measurement significantly
  - All steps are guided by PDA-software -> easy to handle for semi-professional observer
  - Errors can be detected and removed offline
  - 54 different measurements: 30 min, much higher redundancy and data control

Automatic DI Flux: AUTODIF (courtesy J Rasson, Dourbes)



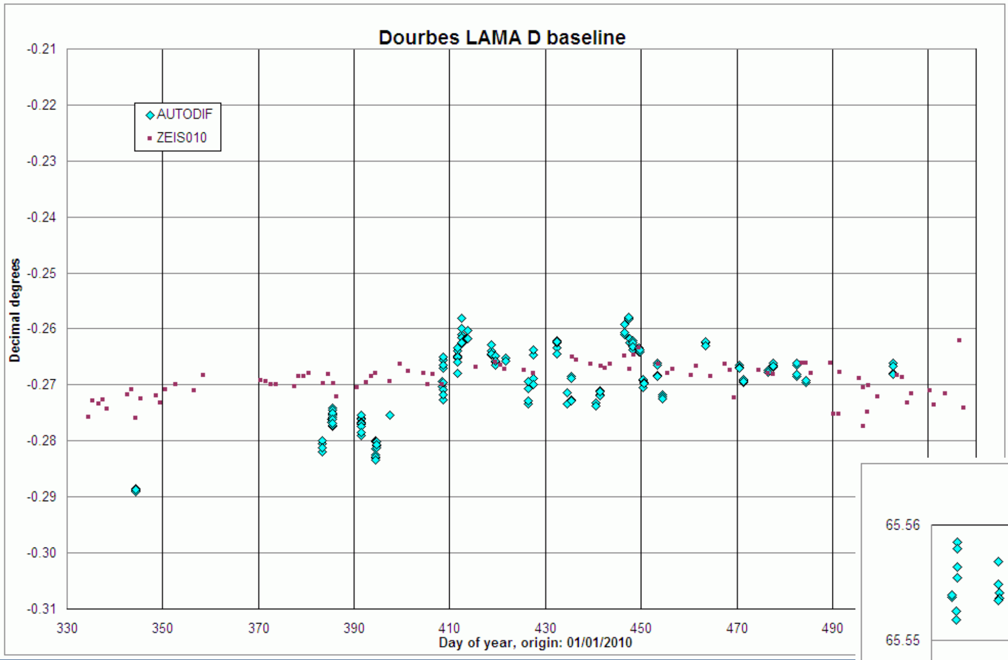


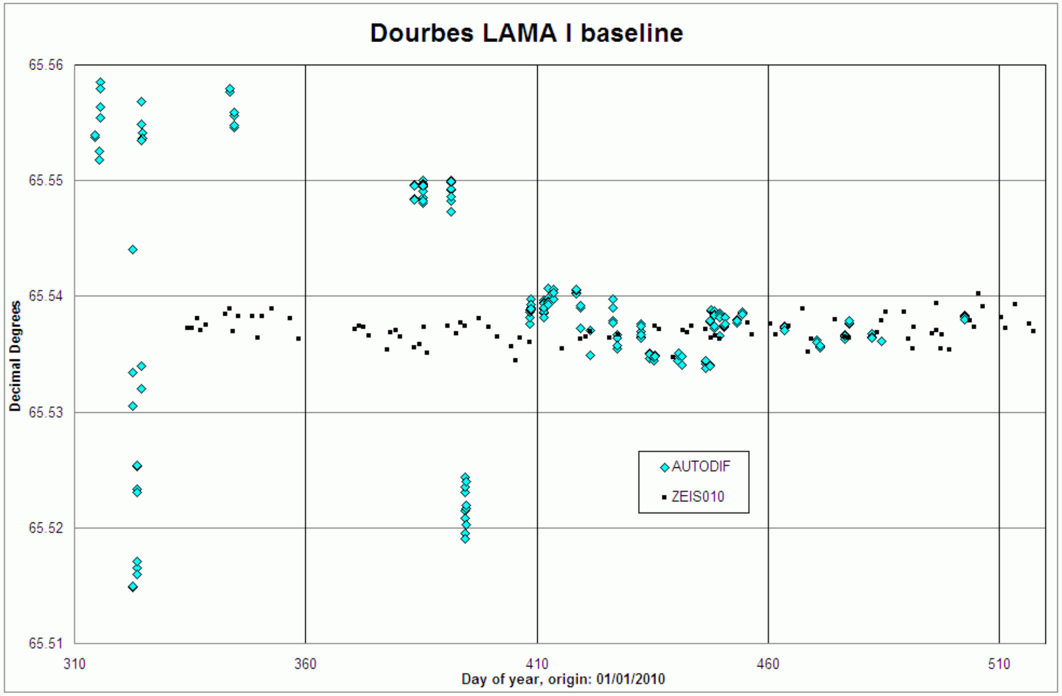
Automatic D & I measurements, no operator interaction needed

Ultrasonic motor drives, accuracy < 1 arc second

Ceramic bearings

Baselines as measured by the AUTODIF MKII and manual observation using a ZEISS010 Diflux. The graphs show the improvement over time regarding the agreement with the ZEIS010. A satisfactory accuracy fine tuning was achieved on day 460, after elimination of small magnetic residual currents and elements.





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Automatic DI Flux: GAUSS (Geomagnetic AUtomatic System)

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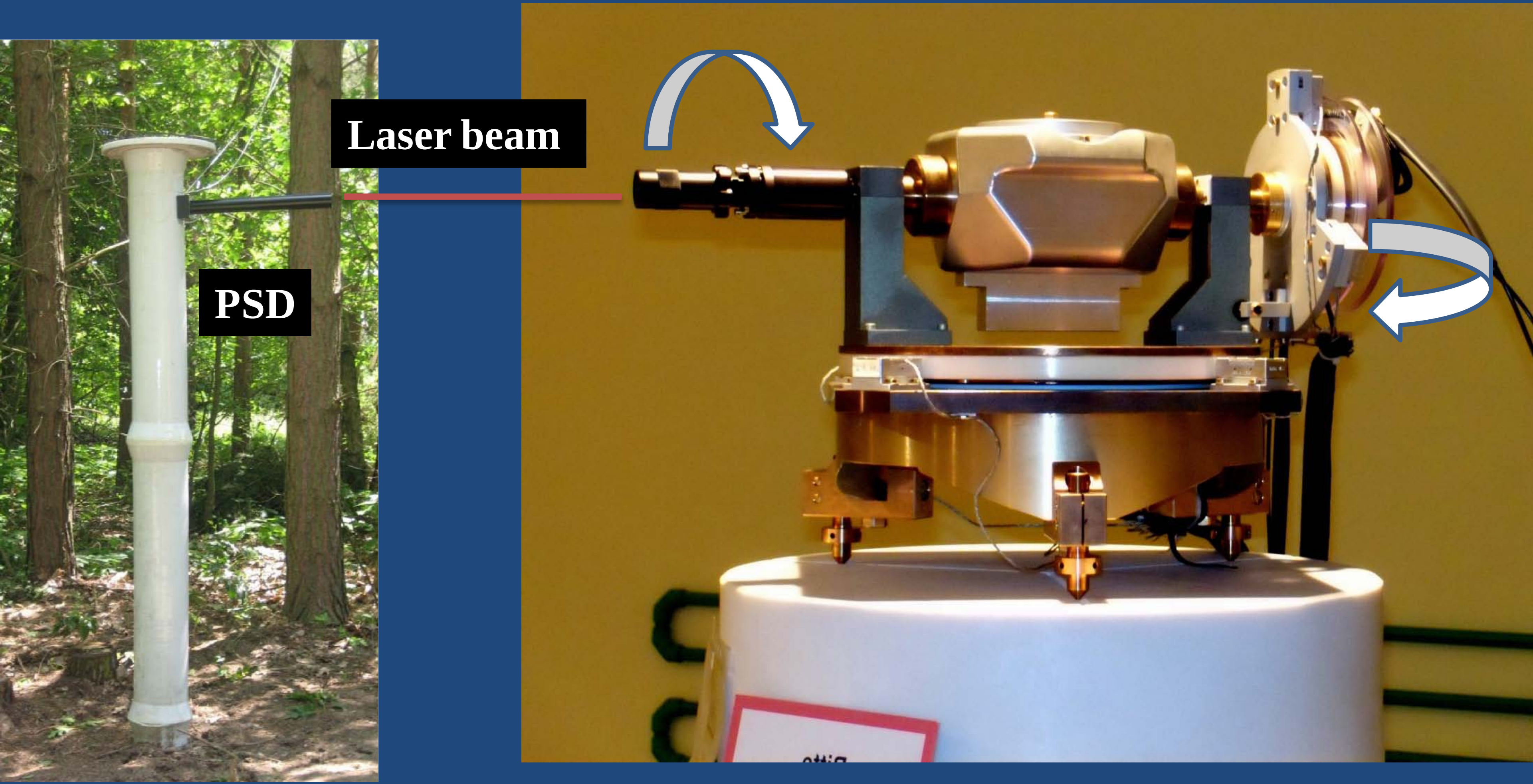
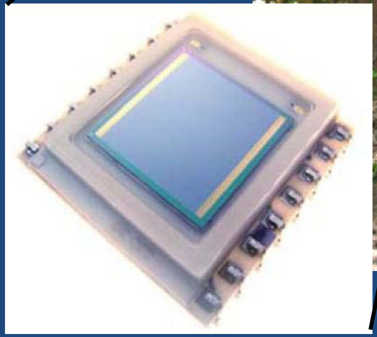


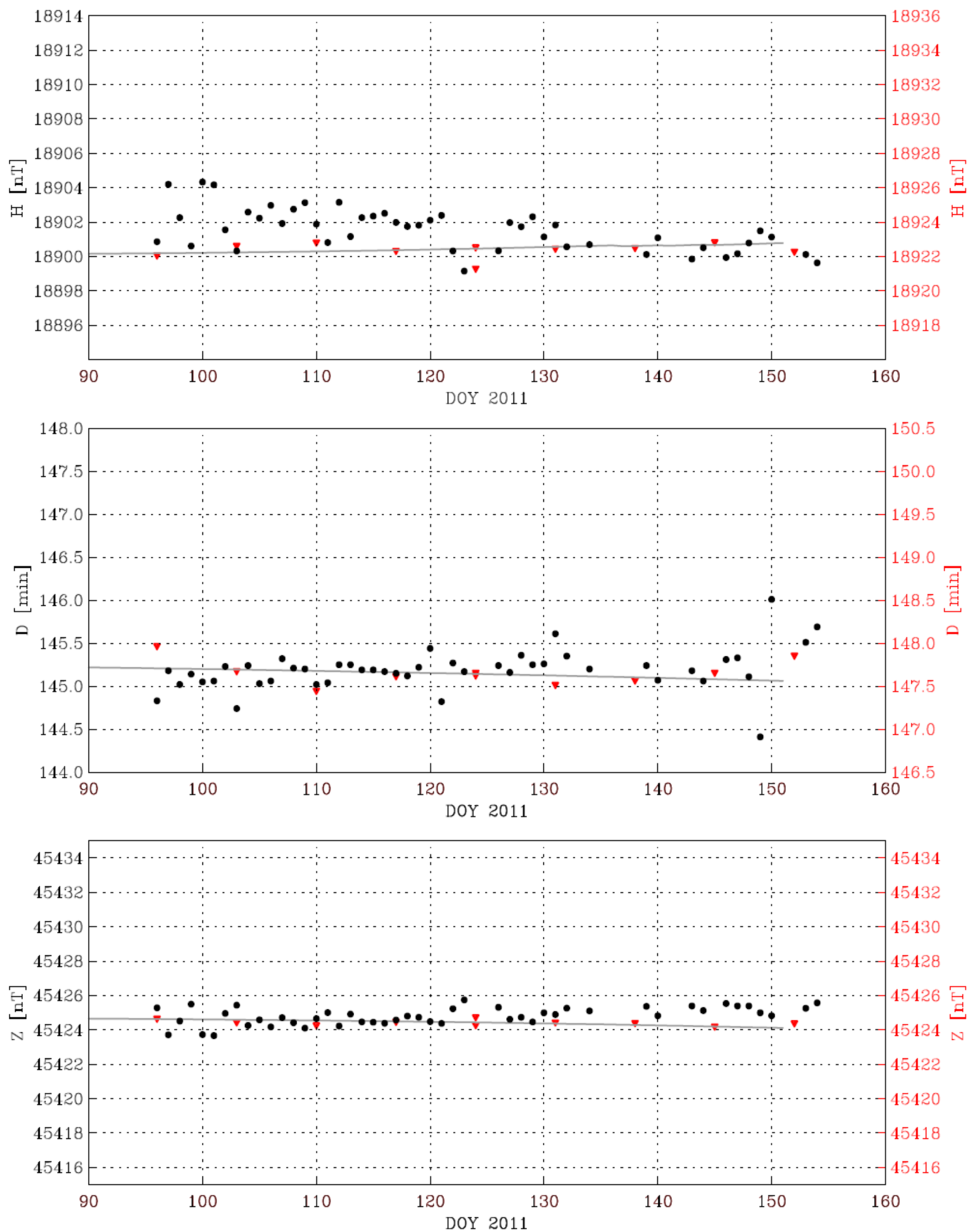
Orientation control

- Laser
- PSD: 2 cm x 2 cm
  - Resolution < 0.1 mm
  - Protected from stray light by filter, black tube
- Azimuth Marks
  - Made by ceramics, grounded in concrete
- Requirements: 1nT ~ 4 arcsec
  - => 0.3 mm resolution at 15 m distance



Results

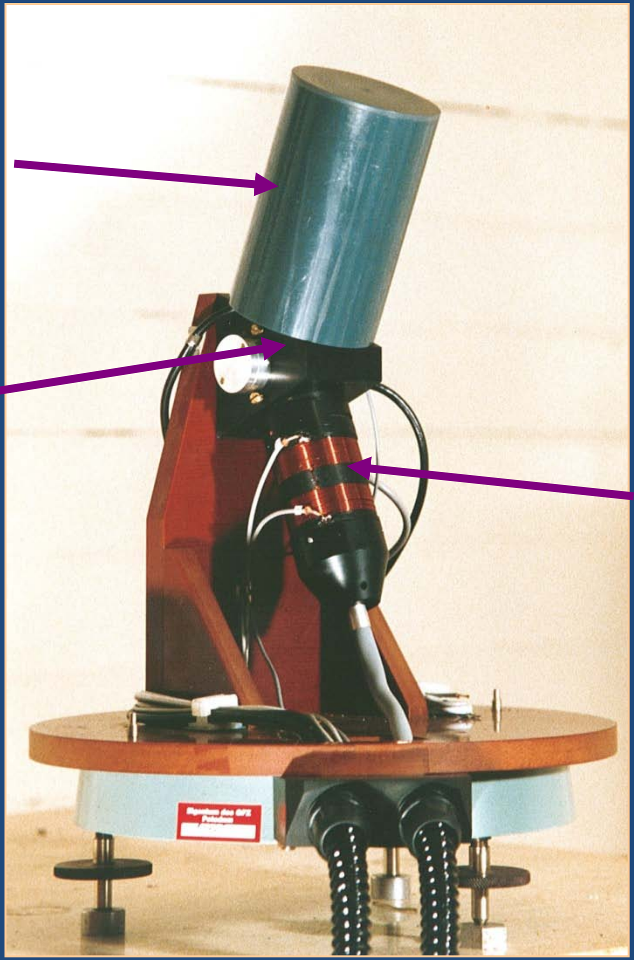
- Measurements each midnight since April 2011
- Comparison to standard DI-flux results
- Scatter in the data mostly acceptable
- A few missing values due to identified, but not yet understood problems (e.g. no signal on PSD; erroneous magnetometer values)
- Some data processing steps very sensitive to initial set-up



New magnetometer instruments

1. Cs-He Optically pumped magnetometer
   (vector information)
2. ^{4}He magnetometer (vector & scalar data)
3. 1 sec Fluxgate-based system (vector data)

Optically pumped Cs-He-Magnetometer

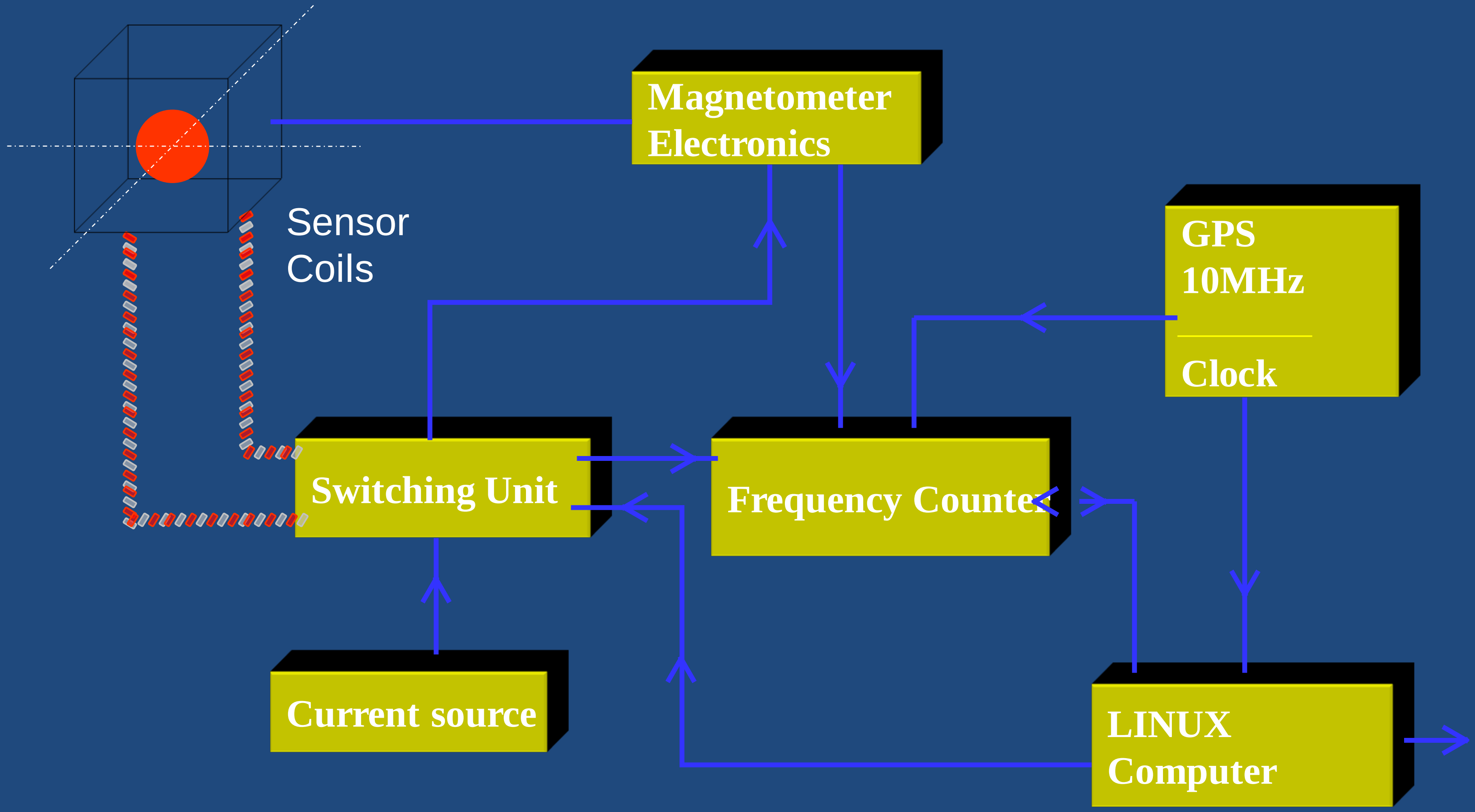


Cs-He- Sensor

Cs - Lamp

Cs- Sensor

Measurement Arrangement



Characteristics

- **Cs-He magnetometer absolute accuracy < 0.1 nT**
  sum of noise at NGK < 5 pT rms
- **Orthogonal coil system: suspended, turnable, LASER controlled**
- **Realtime (GPS) LINUX-controlled system**
- **Result: 1 sec mean values for all components**
- **Reducing the number of manually absolute measurements to some / year**

Optically pumped ^{4}He magnetometer

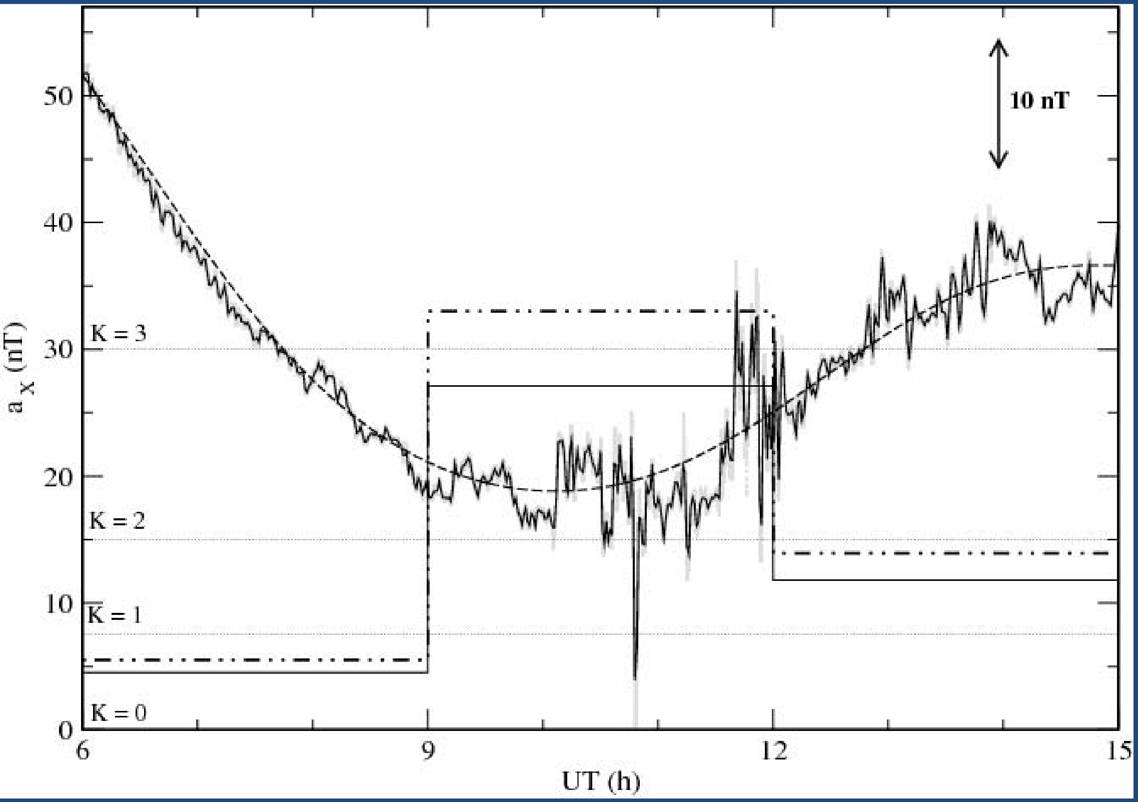
1. Developed by CEA-LETI in Grenoble.
2. Three low frequency AC magnetic fields are applied along mutually orthogonal directions to the helium cell - observatories where absolute measurements would be needed only once or twice a year – fly on SWARM mission
3. Questions about the stability of the coil systems

3-Axis Fluxgate-based LEMI-025

	Data Res	Data Acc	Filter Prefs	Time Acc	Time Pos
Requirement	0.01 nT	NA	Digital	0.01 s	Centered on UT sec
LEMI 025	0.001 nT	0.1%	Digital with linear phase	0.01 s	Centered on UT sec

- GPS synchronization
- IAGA-2002 formatted 1-sec and 1-min data
- FGM Noise level - better than $1pT/Hz^{1/2}$ at 1Hz

New challenges using 1 sec data



Sampling Rate: K indices

K_{60s} are biased downward with respect to K_{1s} by one level in about 12% of the intervals with 98% of these low values occurred at the $K = 0, 1, 2$ levels

Courtesy M Menvielle

Anthropogenic noise in 1 sec data

- Noise in observatory data revealed by 1 sec
- Heavy vehicles
- Modelled by dipole approximation
- The magnetic effect of the vehicles has been approximated by a moving dipole . The disturbance field is expressed in the geographical reference frame by:

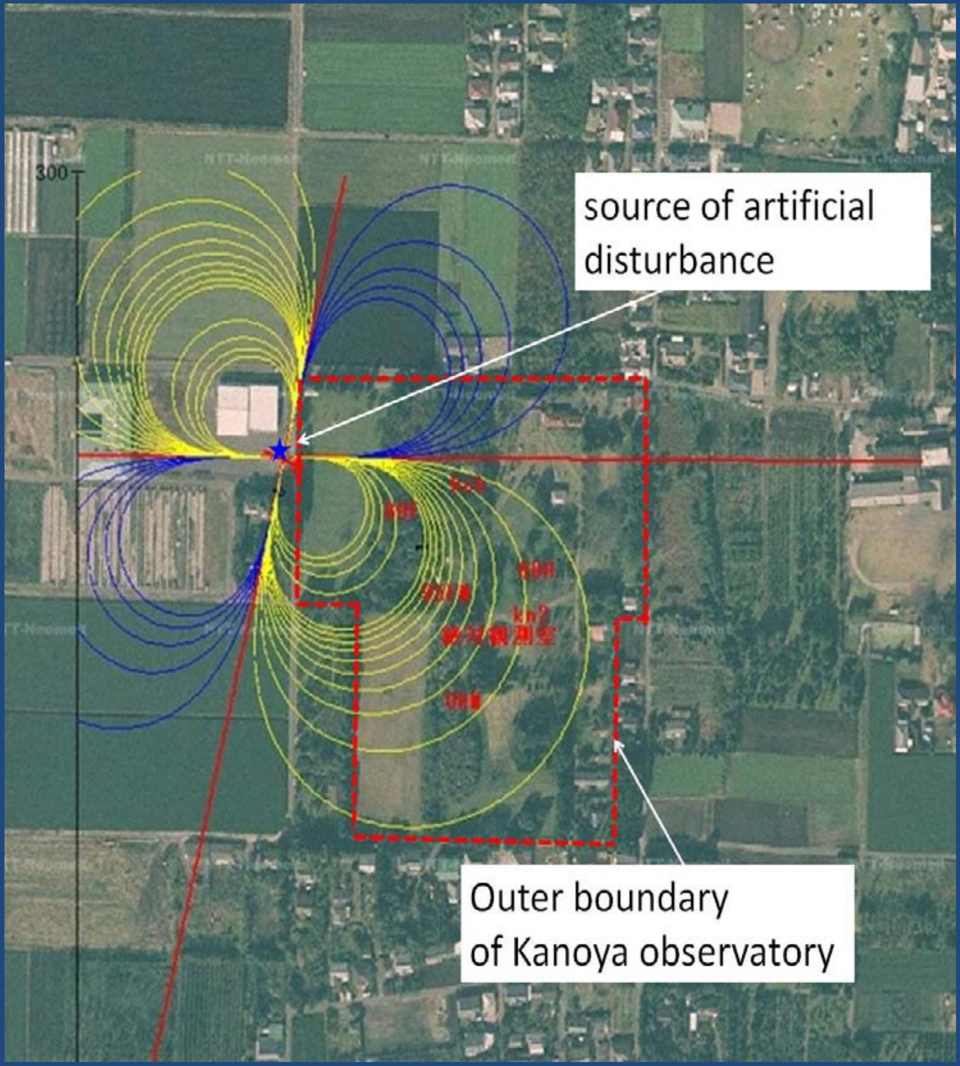
Moving vehicles: dipole modelling

Disturbance effect $S_p = (X_p, Y_p, Z_p)$ **is approximated in geographical reference frame by** $\mathbf{S}_p = \mathbf{A}\ \boldsymbol{M}$ **where M=moving dipole and**

$$A = \frac{\mu_0}{4\pi r^5}\begin{bmatrix} 2X^2 - Y^2 - Z^2 & 3XY & 3XZ \\ 3XY & 2Y^2 - X^2 - Z^2 & 3YZ \\ 3XZ & 3YZ & 2Z^2 - X^2 - Y^2 \end{bmatrix}$$

Important in 1 sec observatory data

Modelling artificial noise: dipole approximation (Kanoya observatory)



Frequency domain method to identify noise in observatory data

With increasing urbanisation, geomagnetic observatories around the world are subject to rising levels of artificial noise from sources such as transportation, communication and power distribution. Conversely, science is demanding that there is better coverage of geomagnetic observatories and that those observatories are capable of measuring higher frequency components of the natural signal with better resolution.

The application of the frequency-domain technique to observatory data shows that this technique is capable of identifying an artificial noise signal.

- **Fourier**
- **Spectrograms**
- **Wavelets**

The frequency-domain technique, however, is limited to detecting periodic noise of amplitude greater than the natural signal amplitude. Hence this technique is insensitive to transient errors in the data, such as spikes or steps.

Regional geomagnetic field modelling

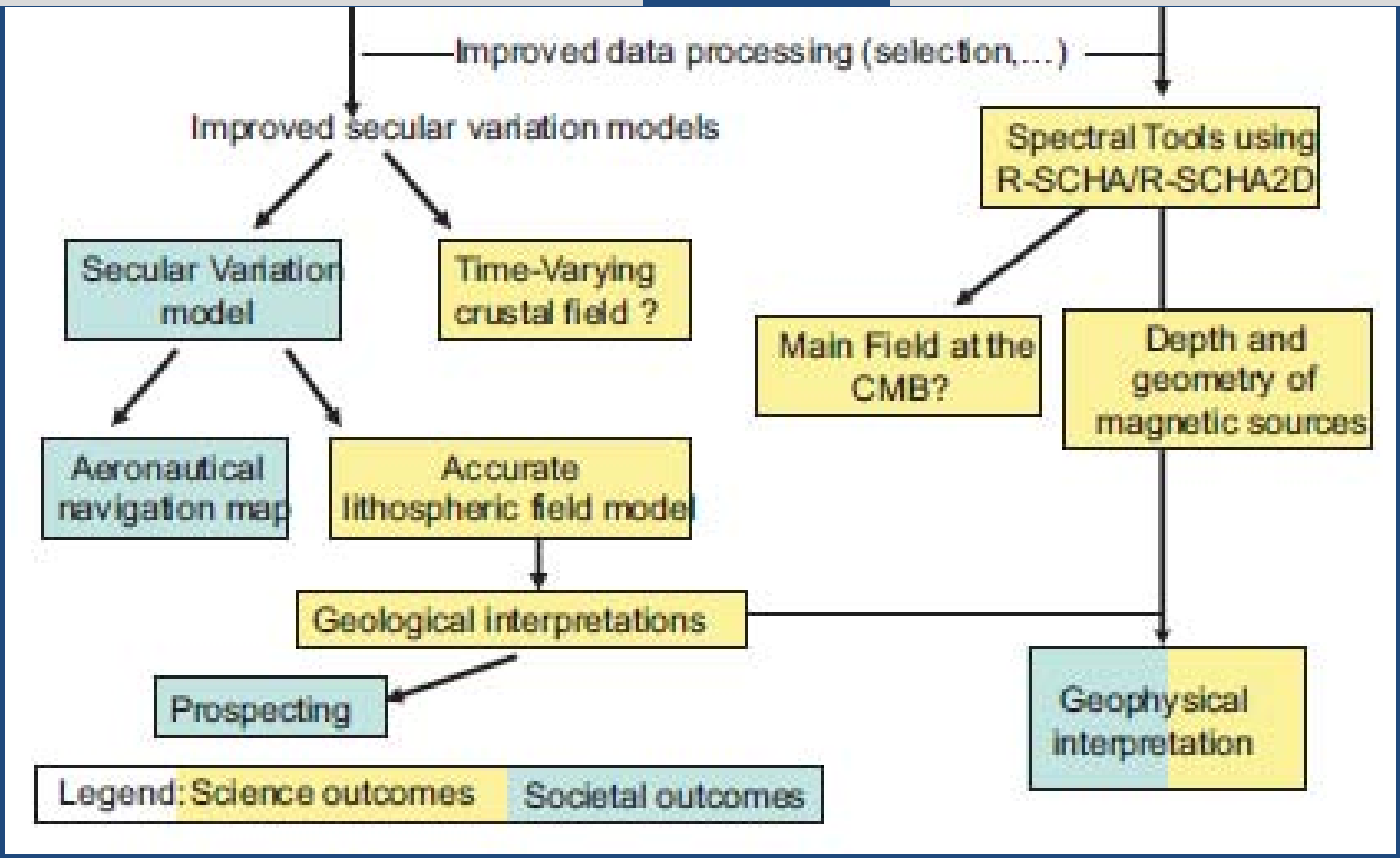
1. R-SCHA (Thébault et al.)
2. Splines (Geese et al.)
    a) Potential field principles
    b) Laplace equation

Scientific Aims:

1. Regional main field model better than global SH models
2. Continuous secular variation (cubic B-splines)
3. Characterisation of lithospheric field

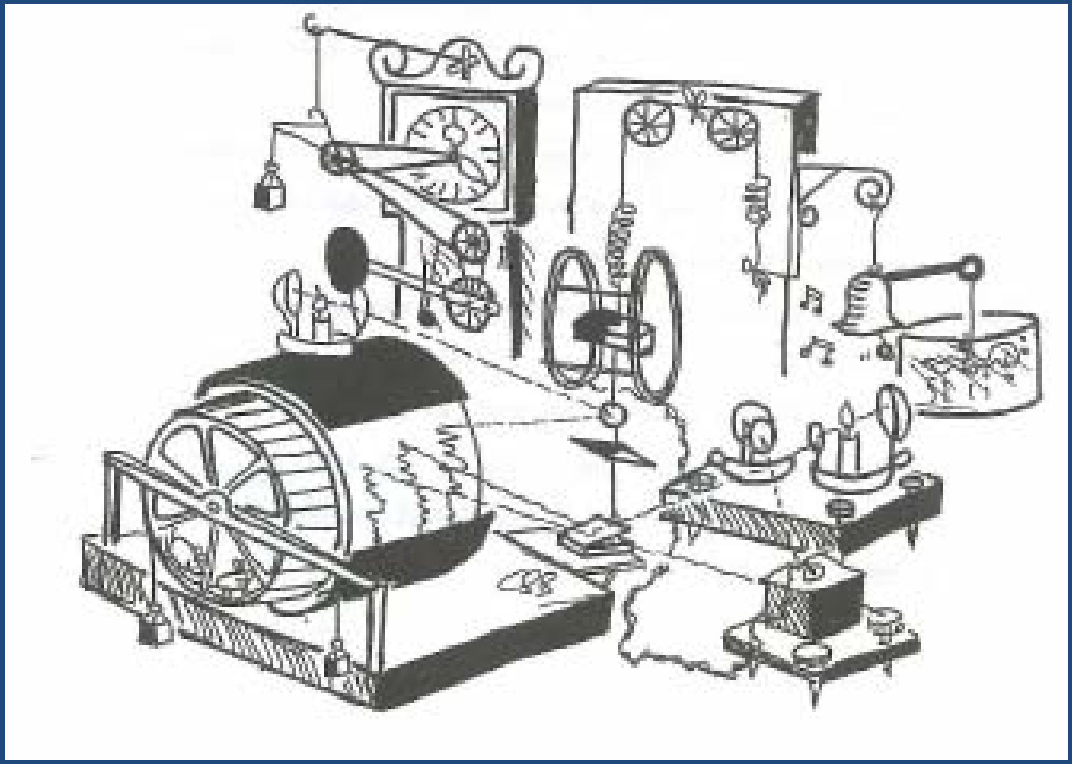
Regional mapping of data

Theoretical approach



Acknowledgements

Everybody who provided information and presentation material.



Thank You

Times have changed !