Geomagnetic Measurements Short Course:

Absolute Procedures for Observatory and Repeat Magnetic Measurements

prepared for the

L M Barreto VIth Latin American School of Geomagnetism - ELAG

November 25th – 30th 2007,

Vassouras, Rio de Janeiro, Brazil

by

Jean RASSON

Royal Meteorological Institute of Belgium

and

Ole RASMUSSEN

Danish Meteorological Institute

Introduction

Magnetic Observatory Basics

Selected DIflux Topics

Total Field Measurements

Computations for Reduction to the Baselines

Special Issues of Repeat Survey Measurements

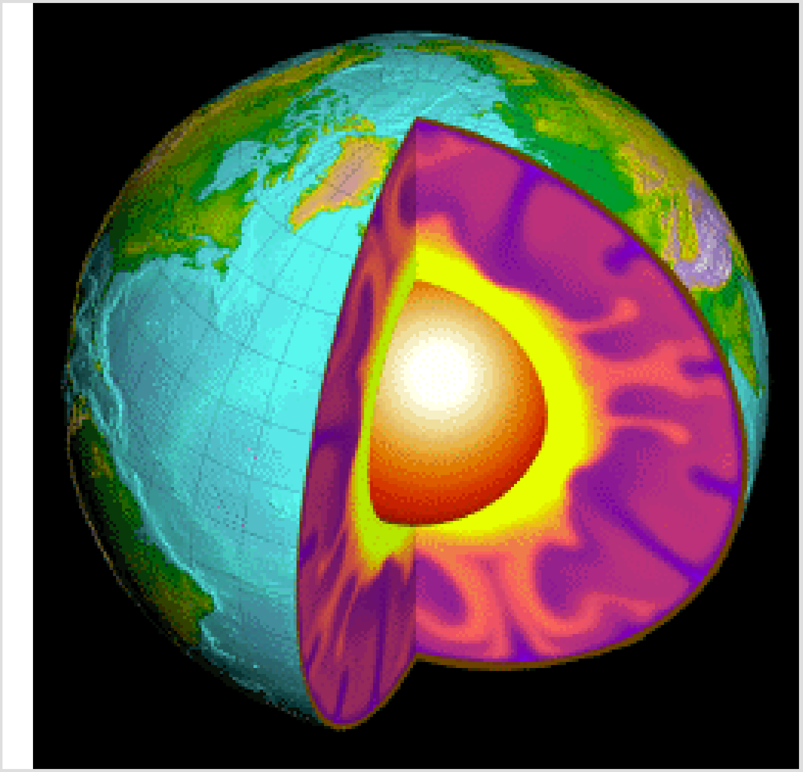
Conclusions

Magnetic Observatory Basics

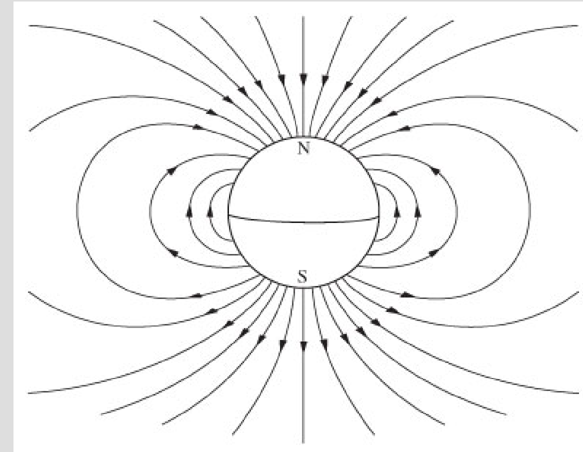
- *Geomagnetic field*
- *Magnetic conditions in Observatory environment*
- *Instrumentation: Absolutes, Variometers*
- *The baseline concept*
- *The DIflux concept*
- *Theo basics: Angle units ; levelling*
- *Diflux measurement protocol*
- *Precautions required for obtaining high accuracy*

Geomagnetic field

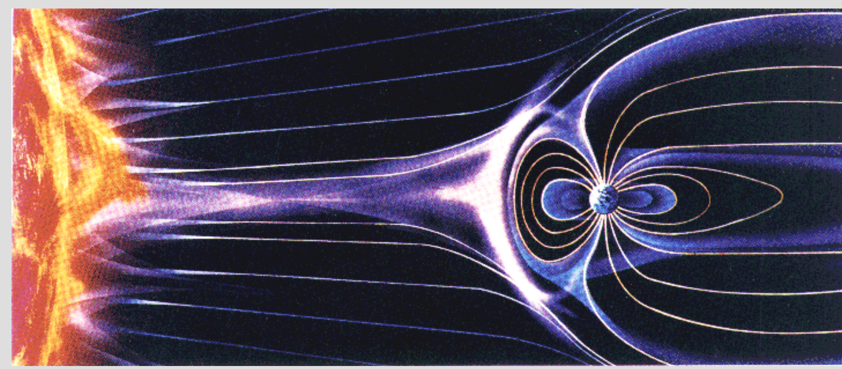
Fluid conducting core



Dipole field



Solar Wind Earth Interaction



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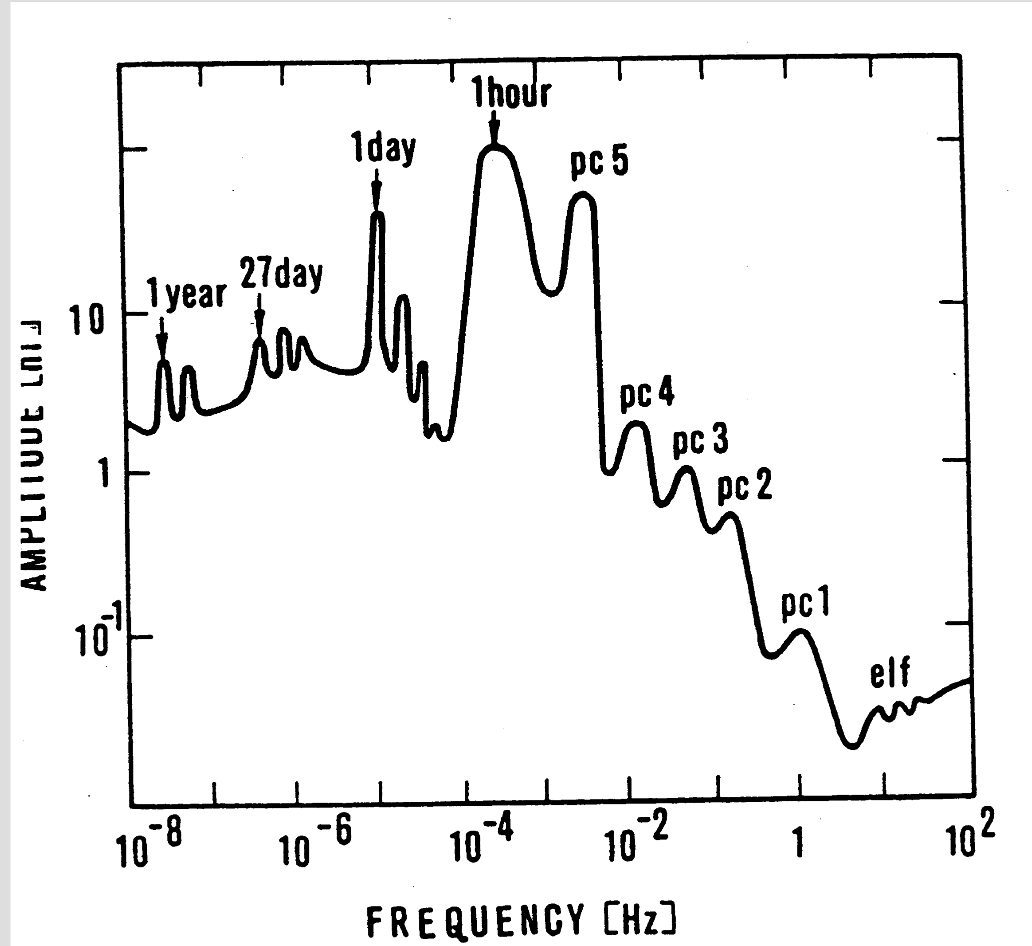
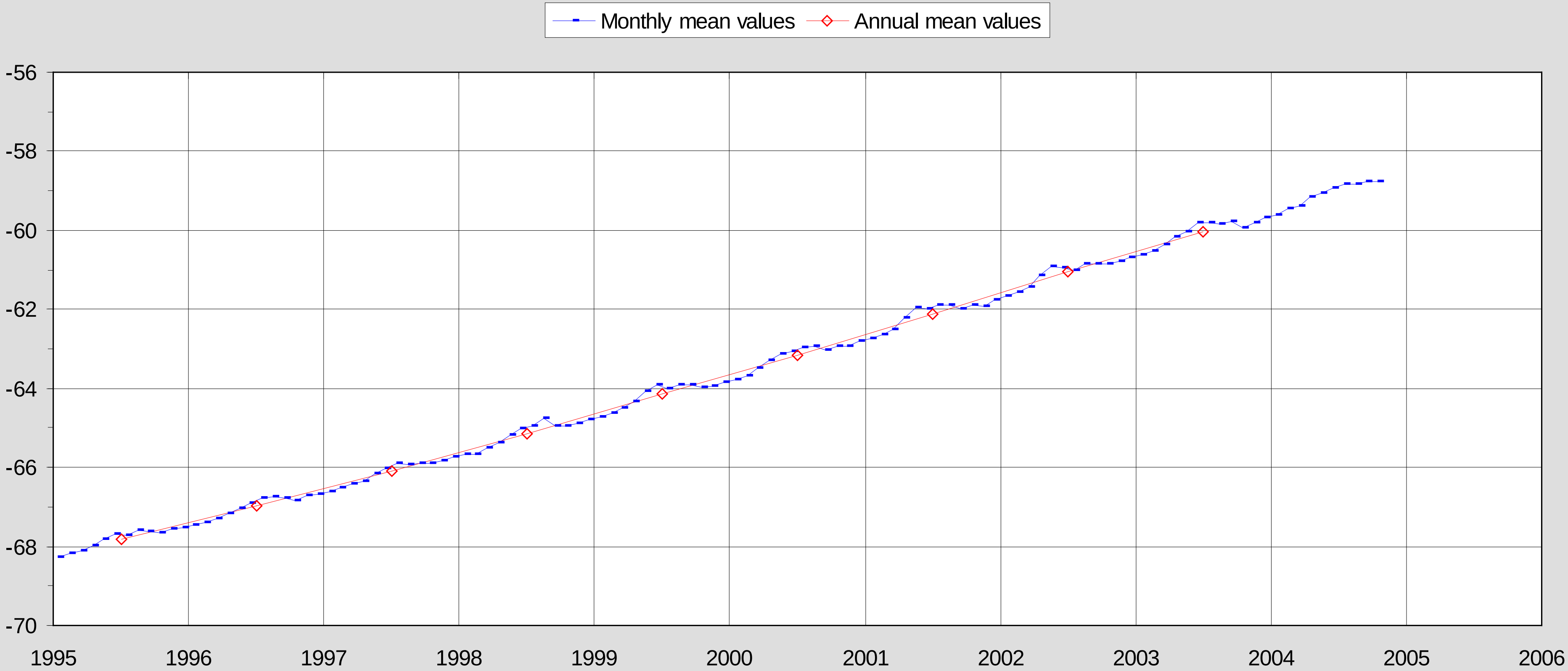
Geomagnetic field

- Secular variations
- Annual variations
- 27 days variation
- Diurnal variation (daily)
- One hour and faster variations



Geomagnetic field , secular and annual variations

Qaanaaq (THL)
Monthly and Annual Mean Values (All Days) of the Declination *D*



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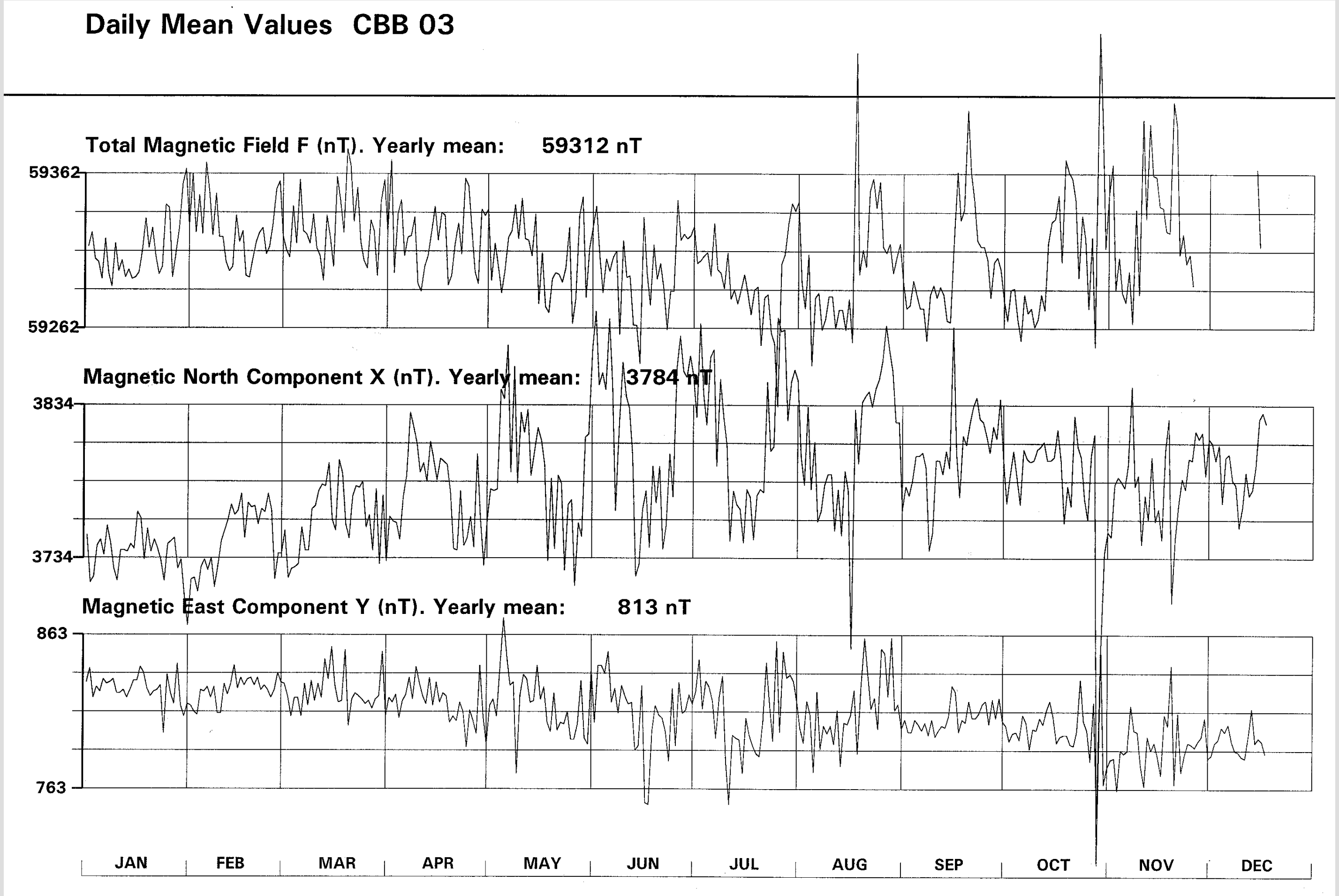
Geomagnetic field Influence of solar wind (27 days)



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Geomagnetic field

Diurnal variation

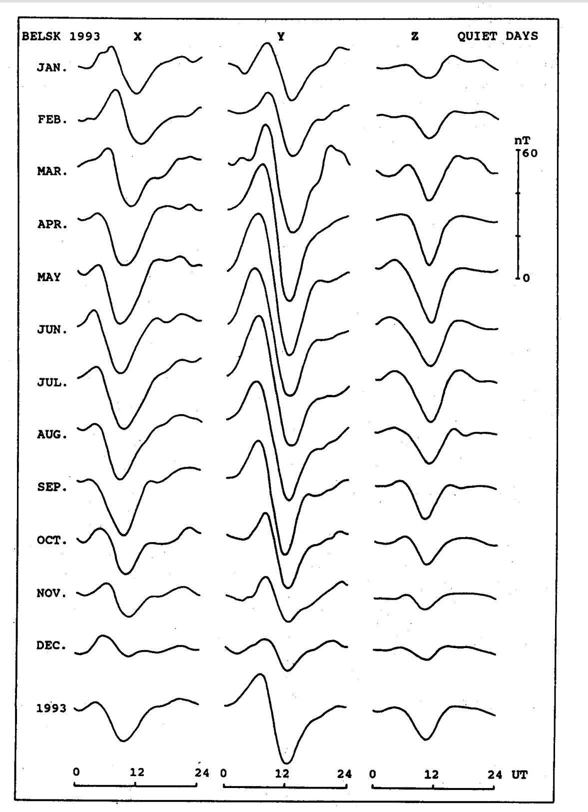
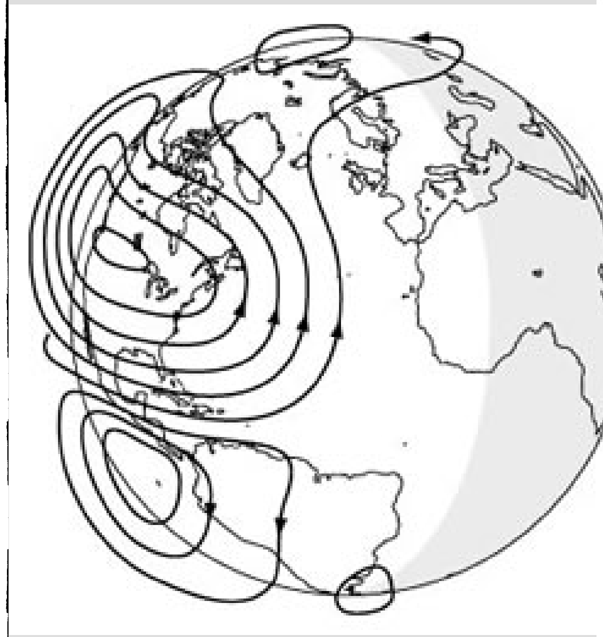


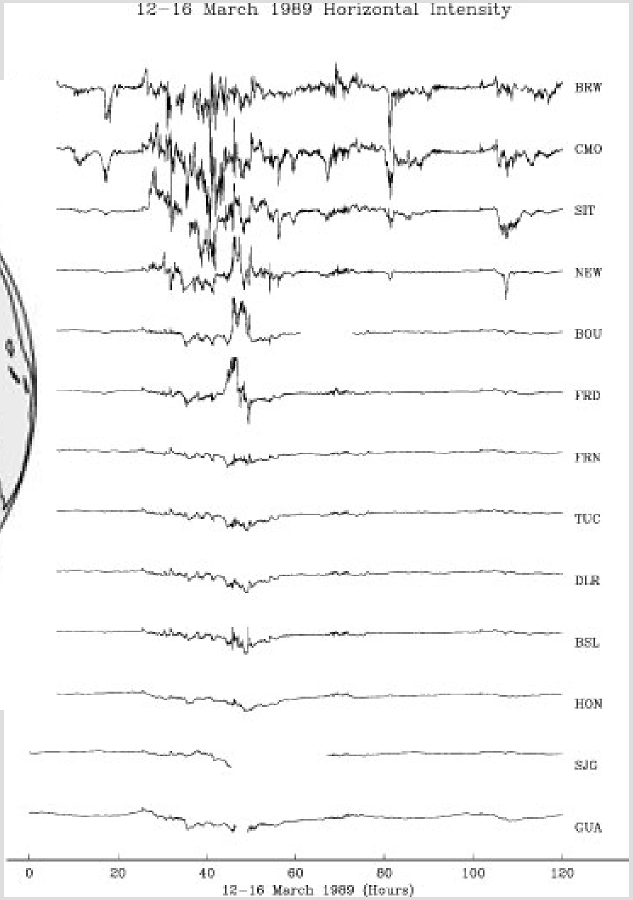
Figure 2.9. Diurnal variation of the magnetic field during solar quiet days (S_q variation) at Belsk observatory for different months of 1993.

Sq currents



http://geomag.usgs.gov/intro.html

Storm variation



http://geomag.usgs.gov/intro.html

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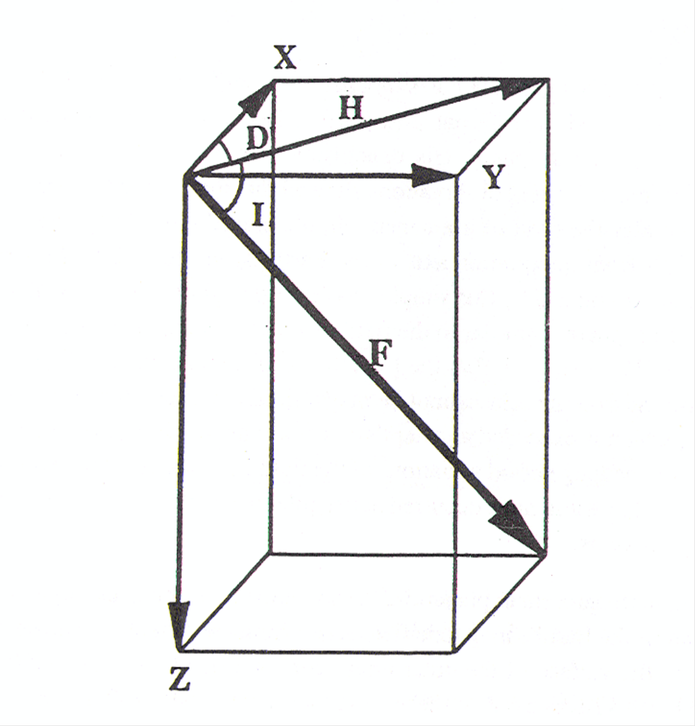
Geomagnetic field

Components and coordinate systems



The Earth Geomagnetic Field is a vector field'

Frame of reference: Geographic North and direction of local gravity

Sets of components used:
XYZ, HDZ, FDI

Components recorded:
XYZ, $H_N H_E Z$, $FH_E V$

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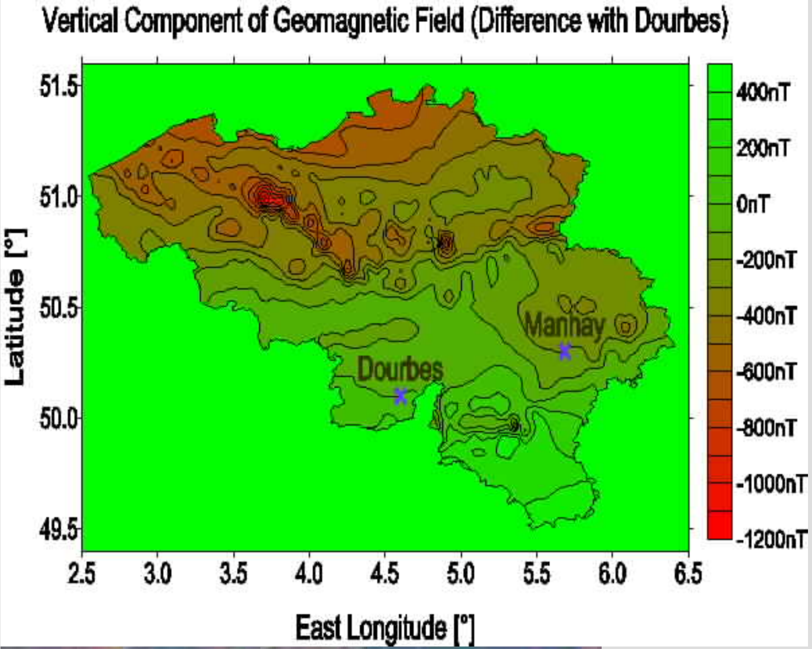
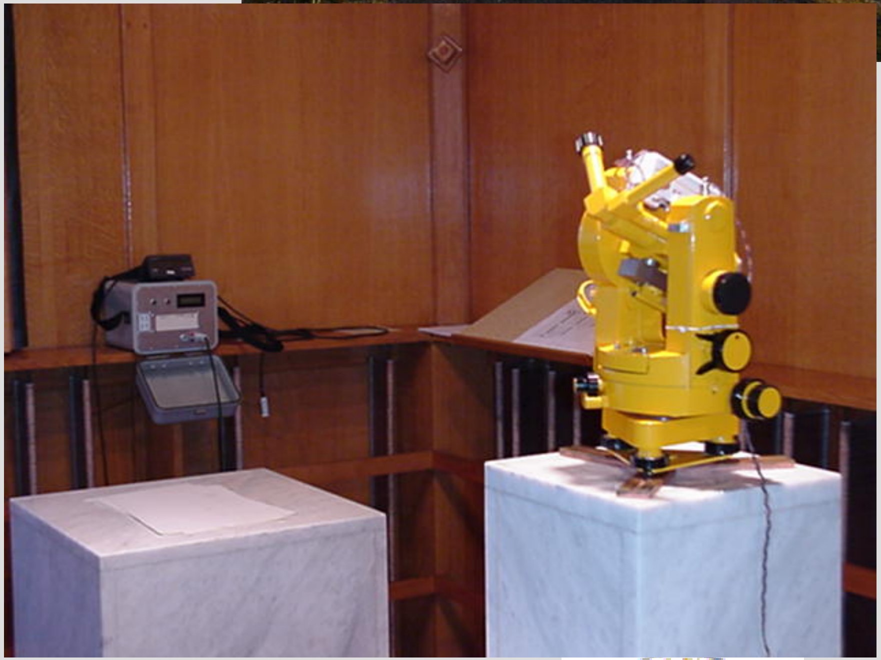
Magnetic conditions in Observatory environment

The Magnetic Observatory is constructed so that:

- It is not situated on a local magnetic anomaly
- All buildings intended for magnetic measurements are non-magnetic





Magnetic conditions in Observatory environment

- Only natural magnetic field is present
- Low magnetic spatial gradient

Consequently:

1. Magnetic field is highly homogeneous: magnetic field lines are parallel
2. Magnetic field differences between pillars are small ($\Delta F \sim 1$ nT)
3. Magnetic field changes are supposed to be identical inside the Observatory space

Additionally:

- Stable pillars
- Availability of targets with known azimuths

Note: Over time, these conditions may degrade. Check them by performing absolutes on more than one pillar!

Instrumentation: Absolutes, Variometers

- Absolute instruments measure one or more components of the Geomagnetic Field in absolute units or the direction of the field with respect to geographic North and direction of gravity

- The classical absolute instruments: Declinometer, Magnetic Theodolite and Vector PPM have been replaced by:

- DIFlux Theodolite for measurement of the Declination angle D and Inclination angle I

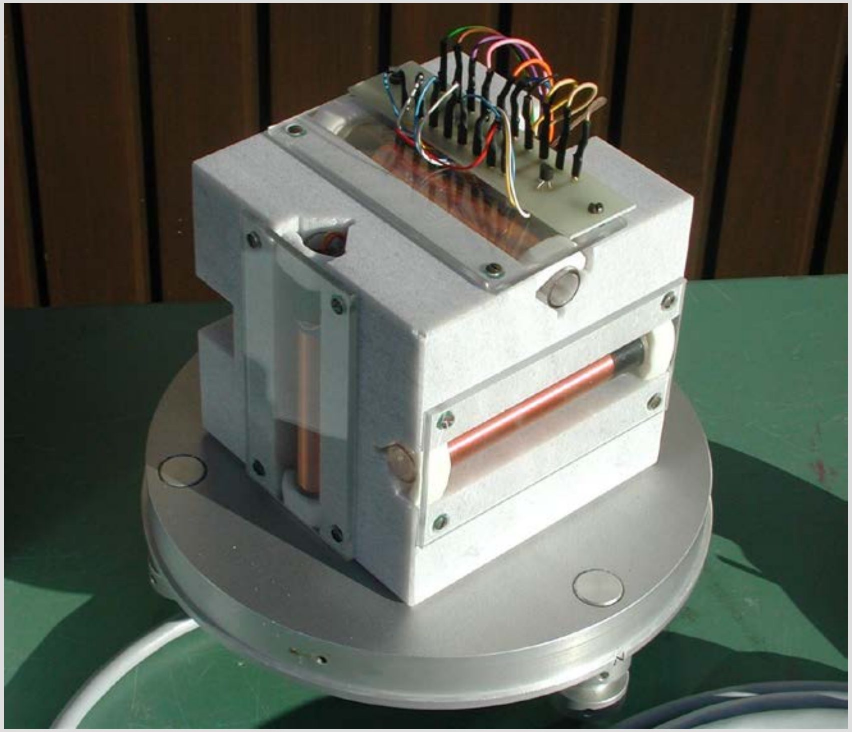
- Proton Precession Magnetometer measures Total Field, F in nT.

Instrumentation: Absolutes, Variometers

A variometer measures the variation of one or more components of the magnetic field in nT.

The variometer measures the field from an unknown level called the baseline.

Modern variometers are:
Fluxgate Magnetometer
Vector Proton / DIDD
Torsion photoelecric magnetometer



Instrumentation: Absolutes, Variometers

- Fluxgate magnetometer
  - Resolution 0.1 to 0.01 nT
  - Sample frequency to 100 Hz
  - Records XYZ, $H_N H_E Z$ or $F H_E V$
  - Tilt compensation
  -
- DIDD proton magnetometer
  - Resolution 0.5 to 0.1 nT
  - Sample frequency to 0.5 Hz
  - Records $H_E V$ and F
  - Tilt compensation

- Torsion photoelecric magnetometer
  - Resolution to 0.01 nT
  - Sample frequency to 1 Hz
  - Records X,Y, Z or H, E, Z
  - Tilt compensation

The Magnetic Observatory Baseline Concept

Fact: Absolute component instruments (Diflux) cannot yet measure continuously. (Total field instrument can)

How to obtain a continuous Geomagnetic recording with absolute quality?

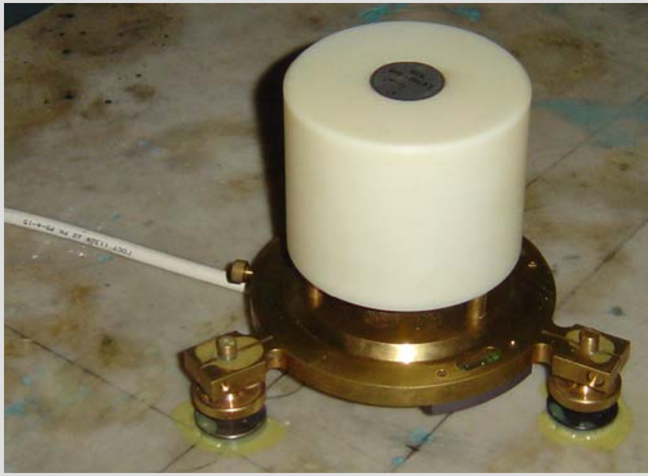
1. Record the variation of the components about a value close to its mean: the baseline. This is done by the variometer
2. Measure from time to time the value of the baseline with an absolute instrument

The Magnetic Observatory Baseline Concept

Exemple

Take the measurements made <u>at the same time</u>:

- Absolute declination measurement D -------------→
- Variometer measurement δD -----------------------→



defines the baseline D_0 :

$$\mathbf{D = D_0 + \delta D}$$

Note 1: This equation can be written for any component

Note 2: Variometer measurements dD and dI in nT are converted to angular units δD and δI by:

$$\delta D = \operatorname{atan}\left(\frac{dD}{H}\right) \qquad \delta I = \operatorname{atan}\left(\frac{dI}{F}\right)$$

The DIflux Concept

Nuovo metodo di misura della declinazione
e della inclinazione magnetica.

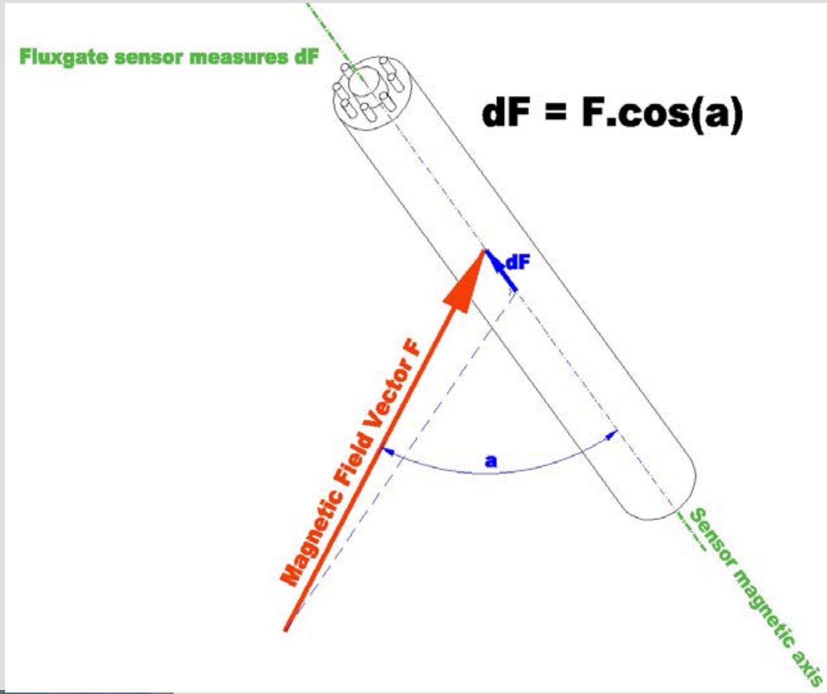
MARIO TENANI

The DIflux Concept

- DIflux is an instrument able to measure the value of the geomagnetic declination D and inclination I.
- The instrument consists of a <u>non-magnetic theodolite</u> and a <u>fluxgate sensor</u> mounted on the telescope, so that optical and magnetic axes are parallel.

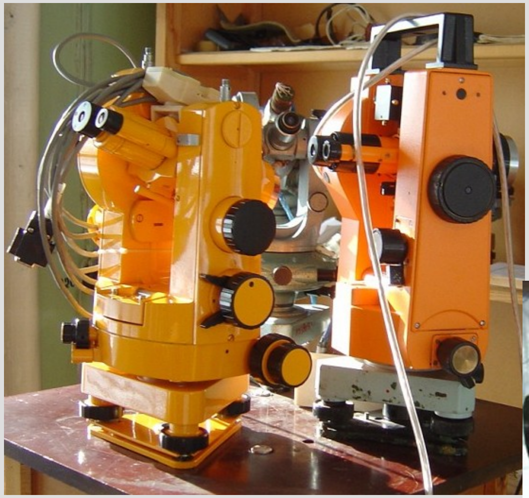
The DIflux Concept

- Fluxgate basics : A fluxgate sensor is very <u>sensitive to its orientation</u> with respect to magnetic field direction. The highest sensitivity is when sensor magnetic axis and magnetic field are almost ⊥ (orthogonal = perpendicular = 2 axis form a 90° angle).



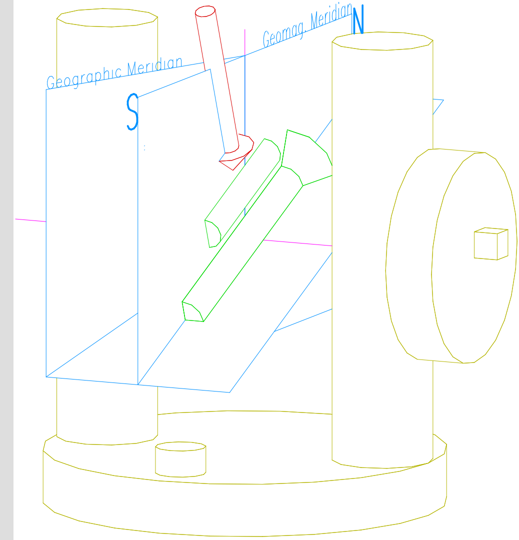
The DIflux Concept

Non-magnetic theodolites (are hard to find)



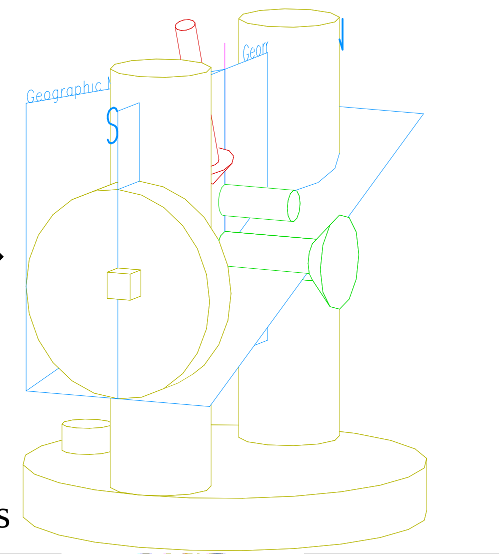
The DIflux Concept

- Determining a plane P ⊥ to the geomagnetic vector is the same as measuring its direction (our task)
- The fluxgate sensor will give null reading when ⊥ to geomagnetic vector
- So we can find the plane P ⊥ to geomagnetic vector: two alignements of the sensor giving a null reading will define it



Here are the 2 usual alignements <u>inside P</u>:

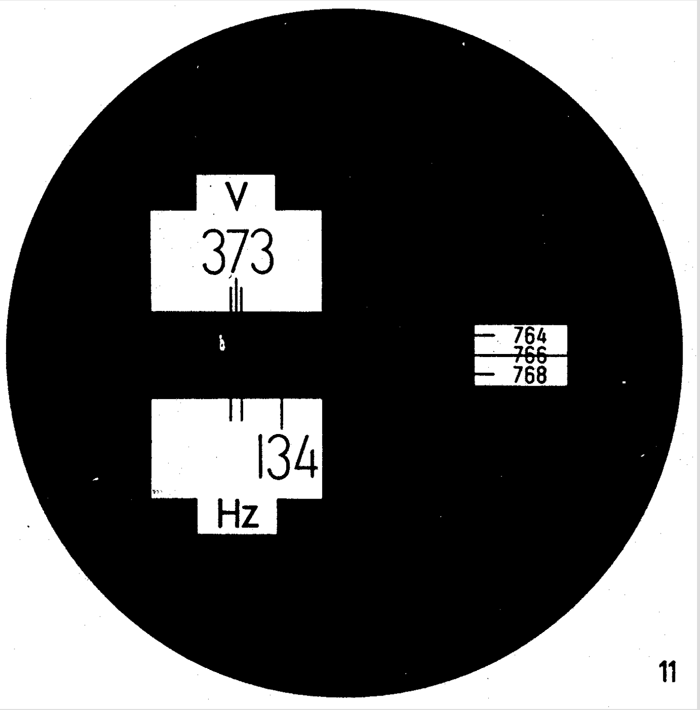
1. We require the sensor to be <u>horizontal</u> : Declination measurement --→
2. We require the sensor to be <u>in the geomagnetic meridian</u> : Inclination measurement (top drawing)



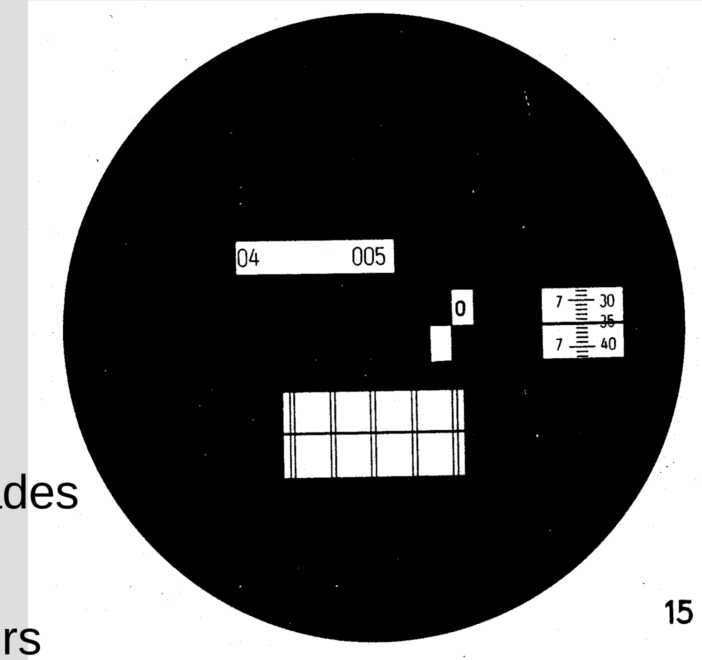
Note : this gives a total of 4 (D) + 4 (I) different positions

Theo basics: Definition of angle units

- Degrees, minutes and seconds
  - 1 turn = 360º 00’ 00’’
  - 1 turn = 360º 00.00’
- Grades
  - 1 turn = 400 grades
- Radians
  - 1 turn = 2*pi= 2*3.1416 radians



Use of Angle Units



005°07’35’’

- Degrees, minute and seconds:
  - Most theodolite circles are divided in DMS.
- Grades:
  - Some Zeiss theodolites circles are divided in grades
- Radian:
  - Computation using software (Excel) and compilers

- 1 sec of arc = 1/200000 rad or 1 mm seen from 200 m distance
- 1 sec of arc movement of magnetic field direction ~ 0.2 - 0.3 nT
- 1 sec of arc change of declination depends on latitude.

Levelling of (Zeiss) Theodolite

- Coarse levelling using circular bubble level
- Accurate levelling using two linear bubble levels
- For best levelling use automatic vertical index

- During normal D and I measurements accurate levelling is not necessary as the build-in vertical compensator can correct for minor tilt of the theodolite.
- A precise levelling however makes the measurements faster.

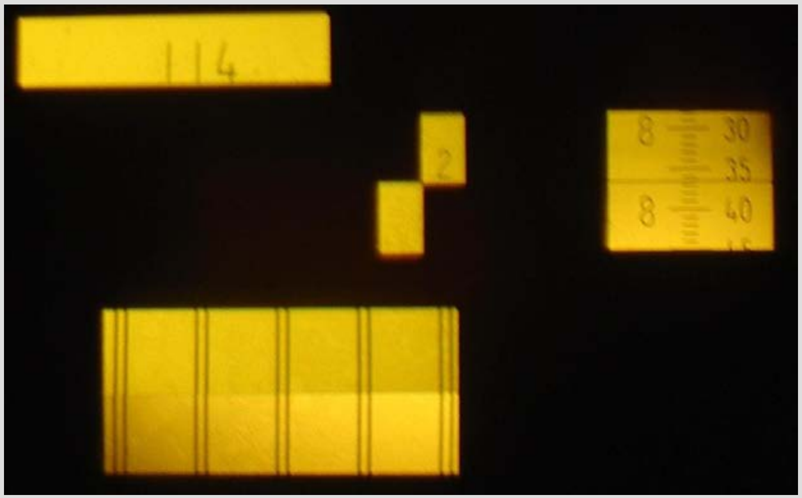
- During measurements with elevated telescope, where readings of both circles are needed (sun and star observations) extremely careful levelling is needed.

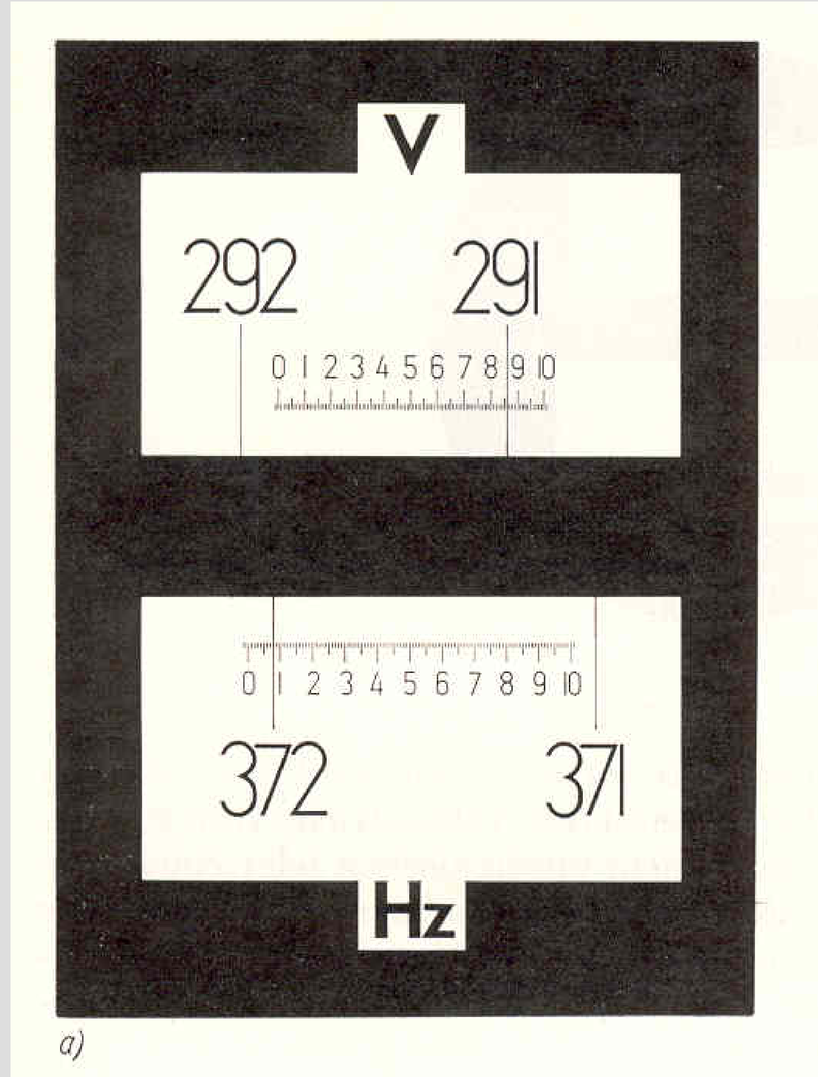
Diflux measurement protocol

The sequence for D measurement positions is as follows:

- Measurement of Azimuth mark sensor up
- Measurement of Azimuth mark sensor down
- D_1 : Telescope horizontal towards E, sensor up
- Test NOW for magnetism of Observer
- D_2 : Telescope horizontal towards W, sensor down
- D_3 : Telescope horizontal towards E, sensor down
- D_4 : Telescope horizontal towards W, sensor up
- Measurement of Azimuth mark sensor up
- Measurement of Azimuth mark sensor down

Diflux measurement protocol





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Diflux measurement protocol

Note: from the D measurement we obtain the direction of the magnetic meridian.

Note: We can orient the theodolite around the vertical axis so that the horizontal axis is $\perp$ to the magnetic meridian: the telescope will then always swing in the magnetic meridian.

The sequence for I measurement positions is then as follows:

- I_5 : Telescope in magnetic meridian pointing towards N, sensor up
- I_6 : Telescope in magnetic meridian pointing towards S, sensor down
- I_7 : Telescope in magnetic meridian pointing towards N, sensor down
- I_8 : Telescope in magnetic meridian pointing towards S, sensor up

Diflux measurement protocol

I_5 : Telescope in magnetic meridian pointing towards N, sensor up

I_6 : Telescope in magnetic meridian pointing towards S, sensor down

I_7 : Telescope in magnetic meridian pointing towards N, sensor down

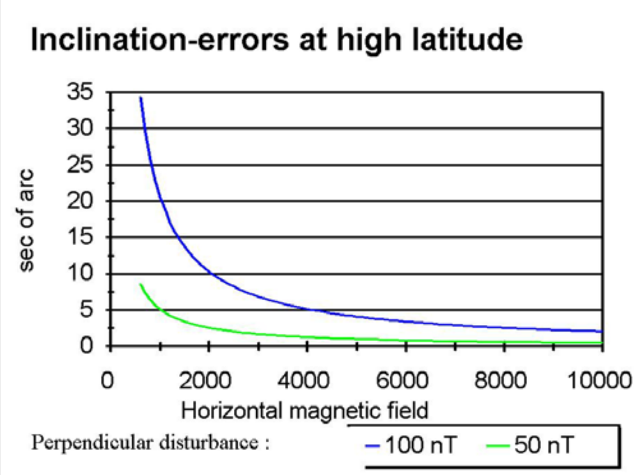
I_8 : Telescope in magnetic meridian pointing towards S, sensor up

Note: in fact we get *two* determinations of I:

$I_H = (I_5 + I_8)/2$ which is the inclination at the “sensor up” position and

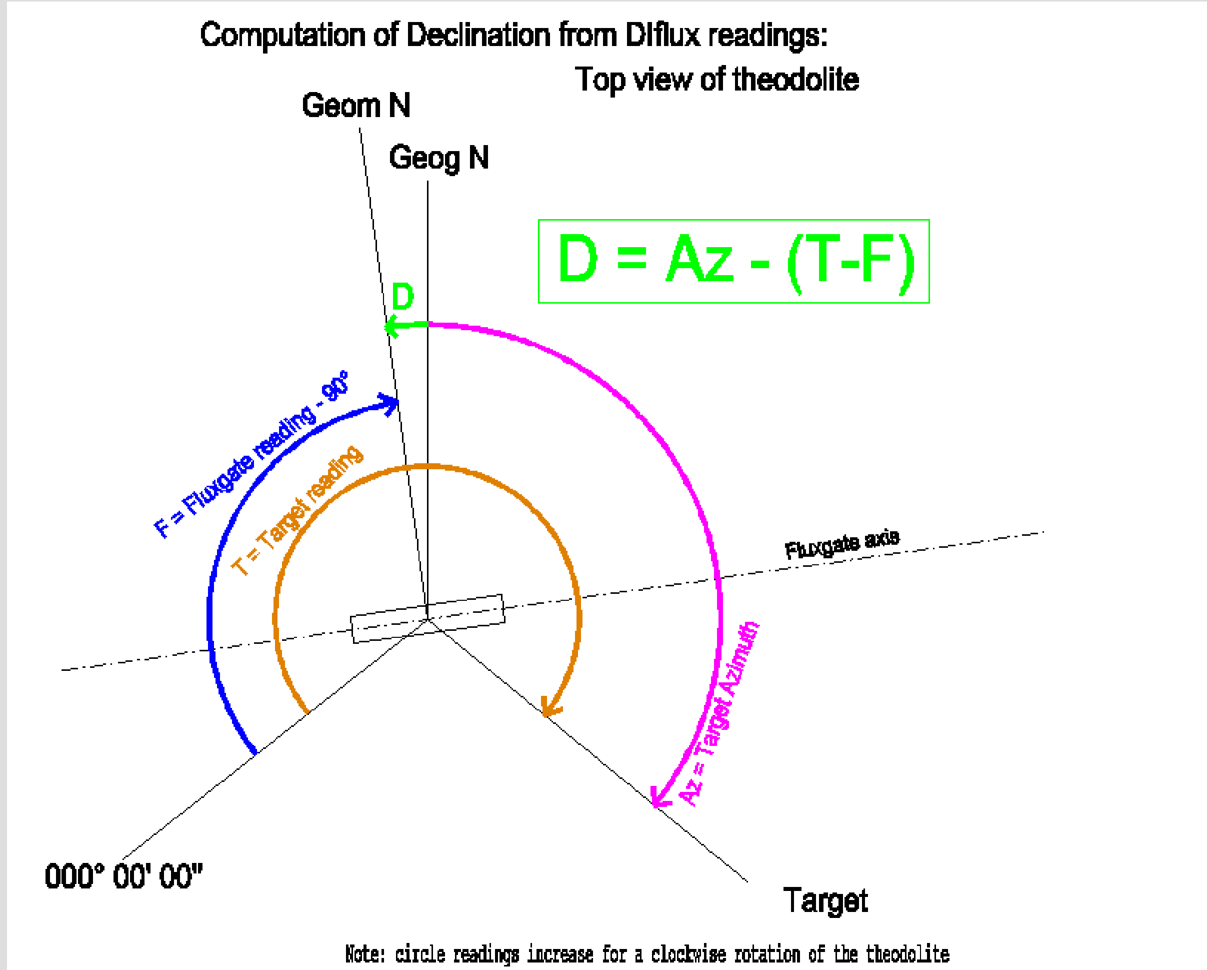
$I_L = (I_6 + I_7)/2$ at the “sensor down” position.

$\Delta I = I_H - I_L$ is called the “I gradient”



We will come back later on ΔI

Diflux measurement protocol



Residual Method

The residual method utilize the digital output of the Diflux to eliminate errors and improve the accuracy of the measurements.

In each of the 4 D and 4 I positions one does not try to adjust the reading to zero but only close to zero (below 10 nT).

On the minute one reads the circles as usual and also the digital output of the DIflux.

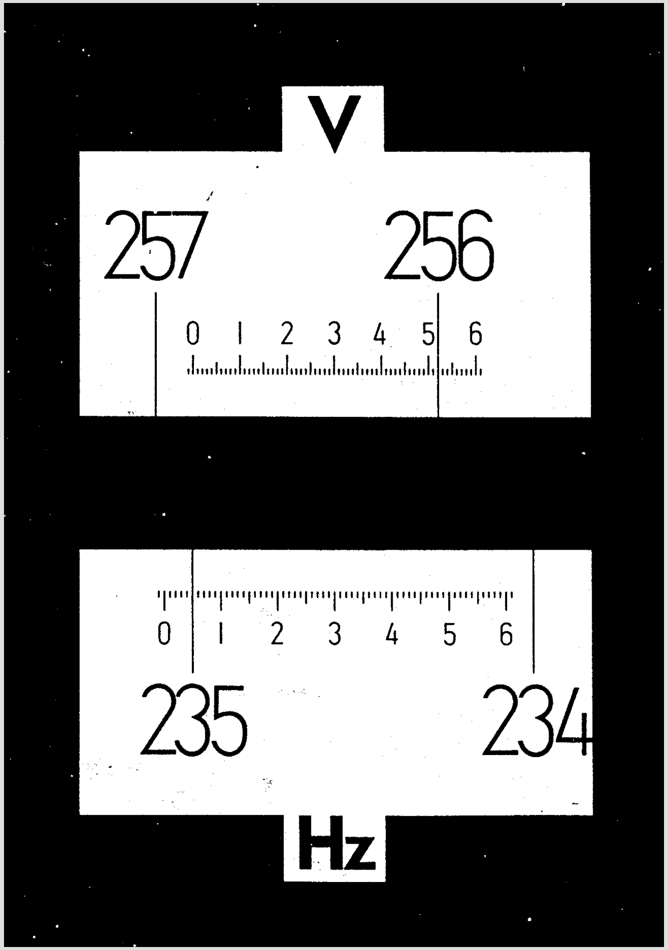
Using to the digital reading from the Diflux, one can calculate the circle readings at zero-output of the Diflux.

Residual Method, advantages

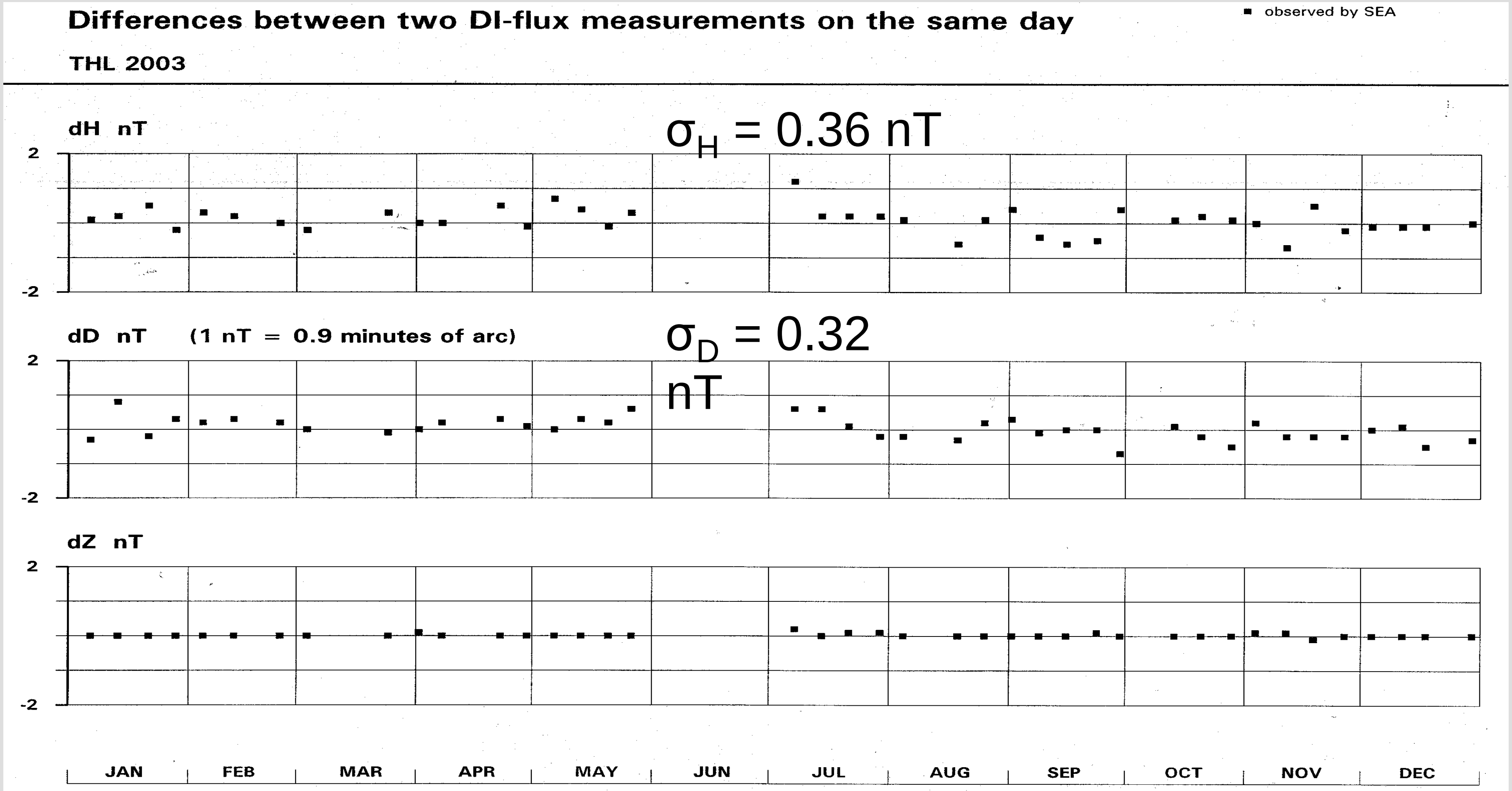
- The observer can step back from the Diflux at the time of measurement and reduce the effect of magnetic contamination from the observer.

- During active period and also at high latitude it is difficult to adjust to 0.0 nT on the minute. This is not needed using the residual method.

- Using difficult to read theodolites like Zeiss 020, one does not have to estimate the value of the fraction of minute of arc. One simply set the circle to 00'' and use the digital reading to calculate the seconds.



Residual Method, precision



$\sigma_H = 0.36$ nT

$\sigma_D = 0.32$ nT

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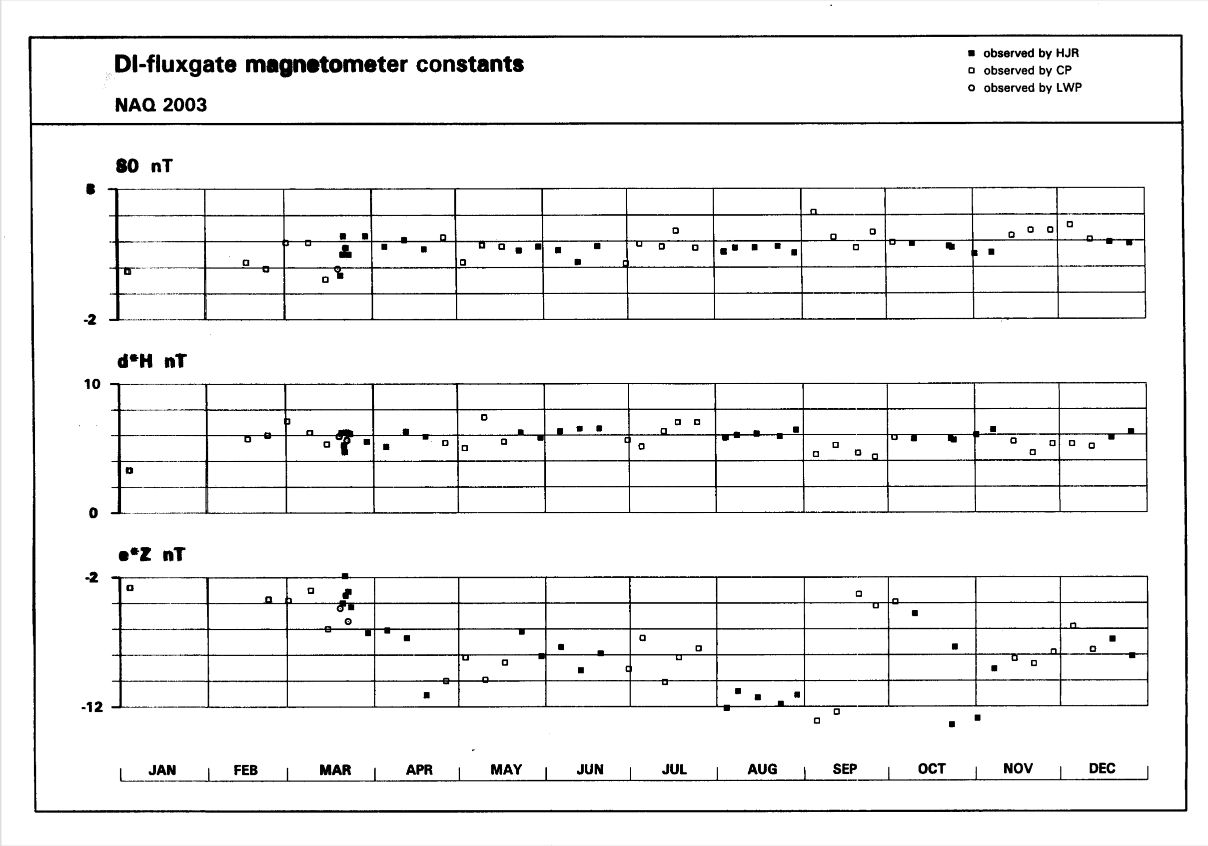
Precautions required for obtaining high accuracy

- ”Clean” environment
  - Absolute house is the ”holy” place in the observatory and should be absolutely clean.
  - Check area around absolute house
- ”Clean” observer
  - Use the Diflux to check for magnetic material. Shoes are often very magnetic.
- Keep observer away from theodolites at the time of reading.
  - Residual method is highly recommended
- Keep good timing < 1 sec
- Use instantaneous variometer data for reduction not filtered minute values
- Keep list af all available data from the absolute observation
  - Baseline values, Absolute values, Temperatures, DI-constants, Observer ID and more
- Continuous check of quality of
  - DI-Thedolite
  - Observer
  - Variometer

Precautions required for obtaining high accuracy

- Diflux constants



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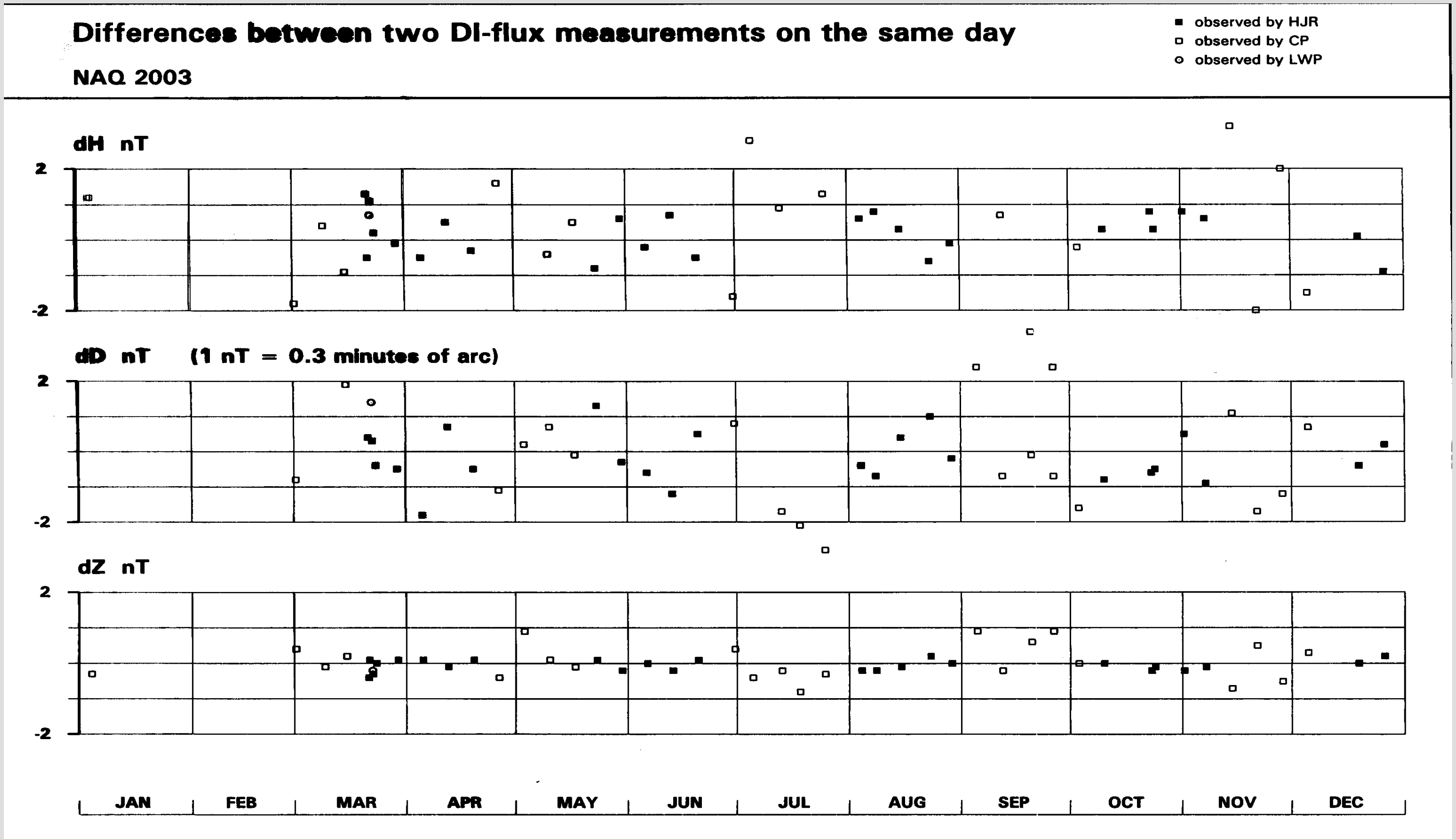
Precautions required for obtaining high accuracy

How good is the observer

ZEISS 020



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