Lecture – Geomagnetic network (instrument and data)

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TRAINING COURSE ON
THE POLAR UPPER ATMOSPHERE: FROM SCIENCE TO OPERATIONAL ISSUES
L'Aquila (Italy), 16-21 Sept. 2018

International School of Space Science
L'AQUILA - ITALY

Istituto Nazionale di Geofisica e Vulcanologia

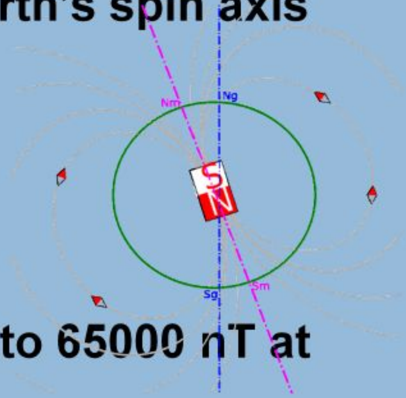
KEY-POINTS (1 of 3):

Our planet has its own magnetic field (known as *geomagnetic field*) since 3.8 billion years and used for navigation in the last 1000 years

About 97-99% of the field can be approximated by a magnetic dipole (at the Earth's surface and for most locations), the *main field* (static or slowly changing)

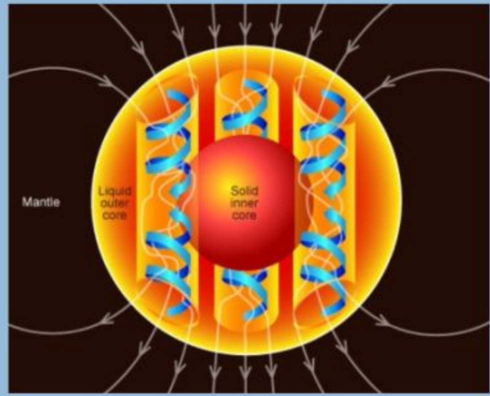
The dipole axis is tilted of an angle of about 9.7° (2015) with respect to the Earth's spin axis

1% - 2% of the field originates in the Earth's crust



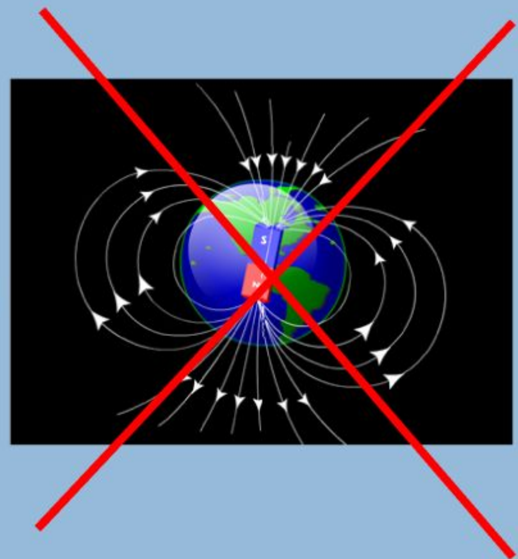
The field intensity at the Earth's surface ranges from 25000 nT at the equator to 65000 nT at the poles

KEY-POINTS (2 of 3):



The field originates in the Earth's outer core, by the motion of electrically conductive fluids (iron, nickel), driven by the heat flow from the inner core to the core-mantle boundary (temperature gradient from about 6000 – 7000 °C to 3800 °C)

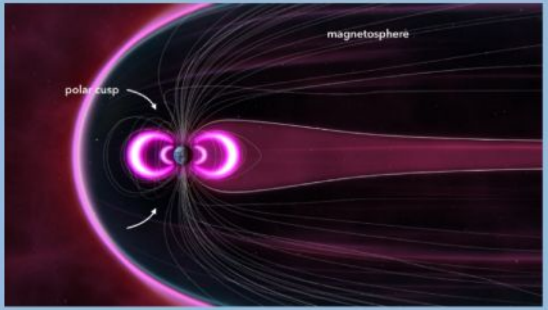
The remaining part is due to the magnetic external field (interaction between the interplanetary and the Earth's magnetic field) + minor contributions from the induction effect into the Earth due to the short time variations



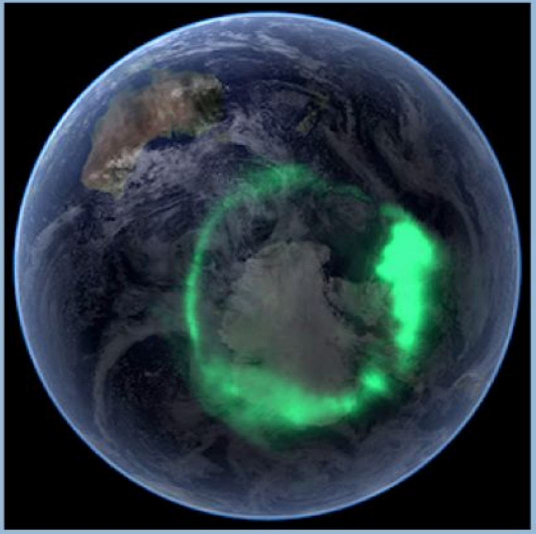
No *permanent magnet* inside the Earth because of Curie temperature (at the depth of 25 km from the Earth surface the Curie temperature is reached for almost all the magnetic material)

KEY-POINTS (3 of 3):

The interaction between the interplanetary magnetic field (IMF) and the Earth's magnetic field confines the magnetosphere in a donut-shaped, asymmetric region (with extension of 10 Earth radii sunward and 200 Earth radii in the opposite direction towards the magnetotail)



When the solar wind becomes stronger, following the solar cycle, the interaction may become unstable and geomagnetic storms can be triggered with the generation of some phenomena (like the auroras) studied by a new discipline, the *Space Weather*

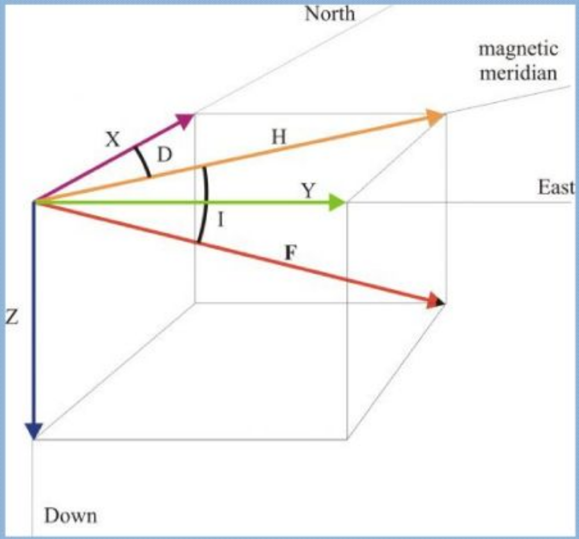


At any location on the Earth, the magnetic field can be represented by a three-dimensional vector. A typical procedure for measuring its direction is to use a compass to determine the direction of magnetic North. Its angle relative to true North is the *Declination* (*D*). Facing magnetic North, the angle the field makes with the horizontal tangent plane is the *inclination*(*I*) or ***magnetic dip***. The *intensity* (*F*) of the field is proportional to the force it exerts on a magnet.

The geocentric components of the geomagnetic field in the northward, eastward, and radially inwards directions (X, Y and Z) are obtained from the global models coefficients (like IGRF) by taking the gradient of a scalar potential V (from spherical harmonic analysis) in spherical polar coordinates:

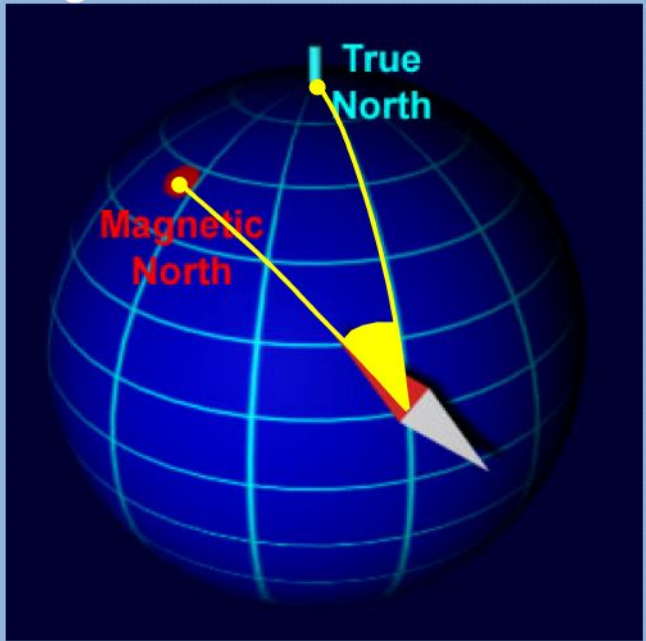
$$X = \frac{1}{r}\frac{\partial V}{\partial \theta}, \quad Y = -\frac{1}{r\sin\theta}\frac{\partial V}{\partial \phi}, \quad Z = \frac{\partial V}{\partial r}$$

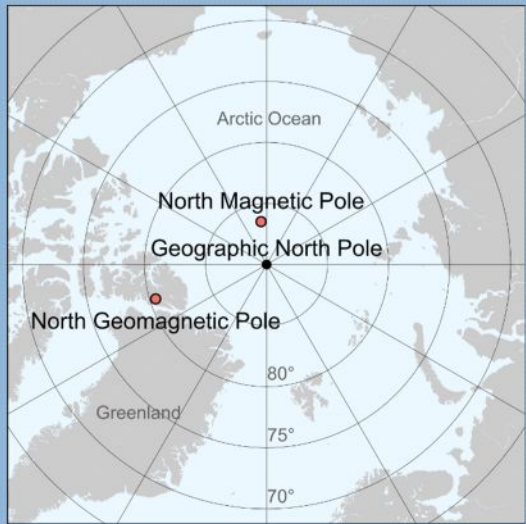
Another common representation is in *X* (North), *Y* (East) and *Z* (Down) coordinates.



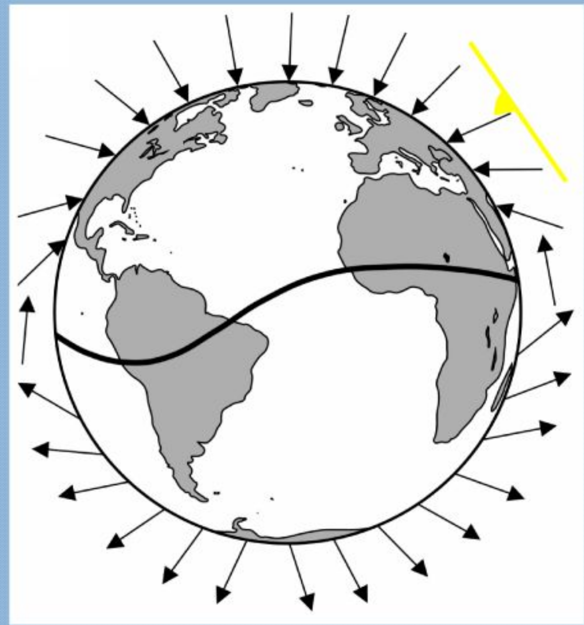
$$H = \sqrt{X^2 + Y^2}, \quad F = \sqrt{X^2 + Y^2 + Z^2},$$
$$D = \arctan(Y/X), \quad I = \arctan(Z/H).$$

Magnetic declination: angle between true North and magnetic North

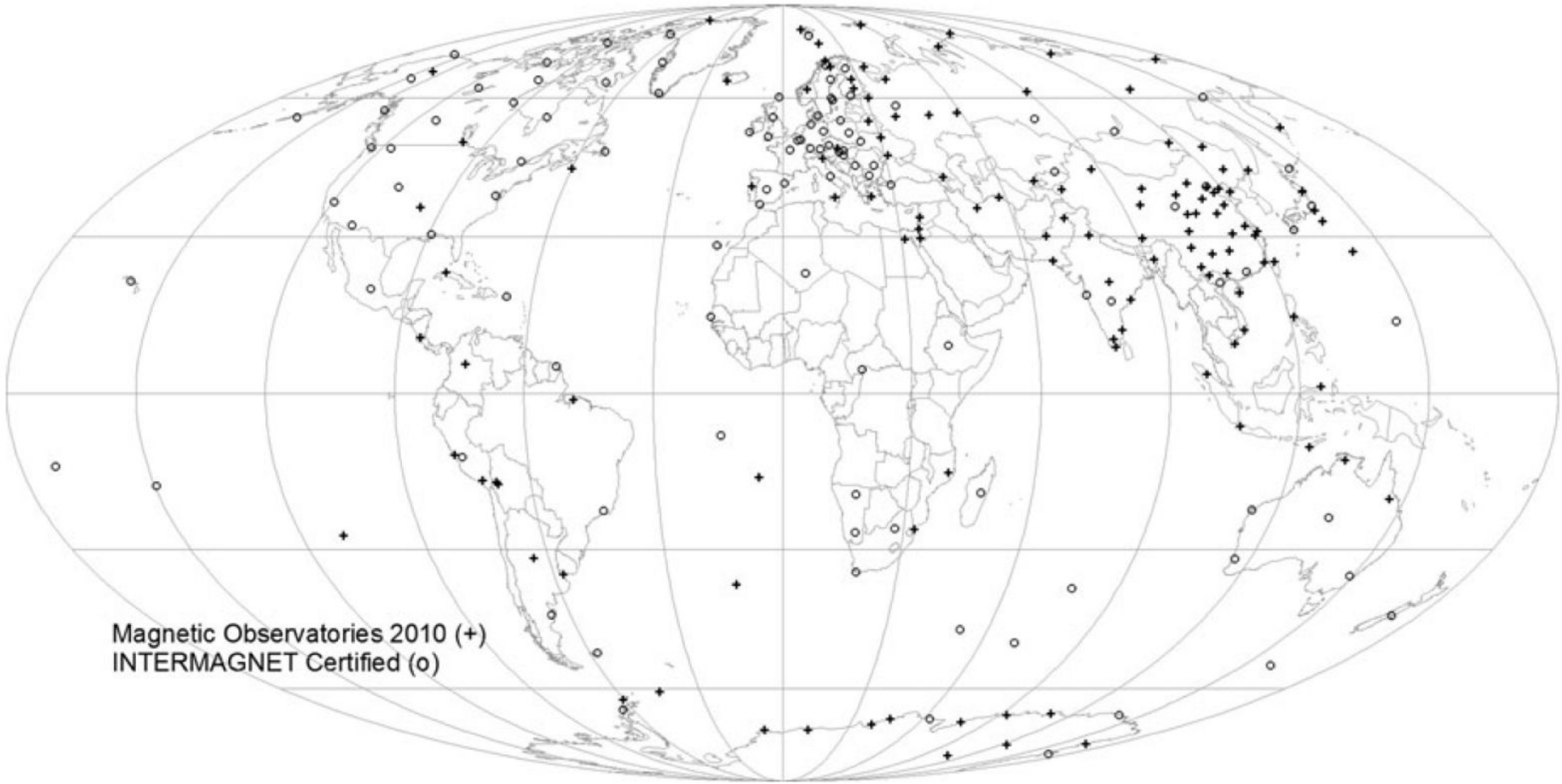




Magnetic inclination: angle between a tangential plane and the direction of vector F

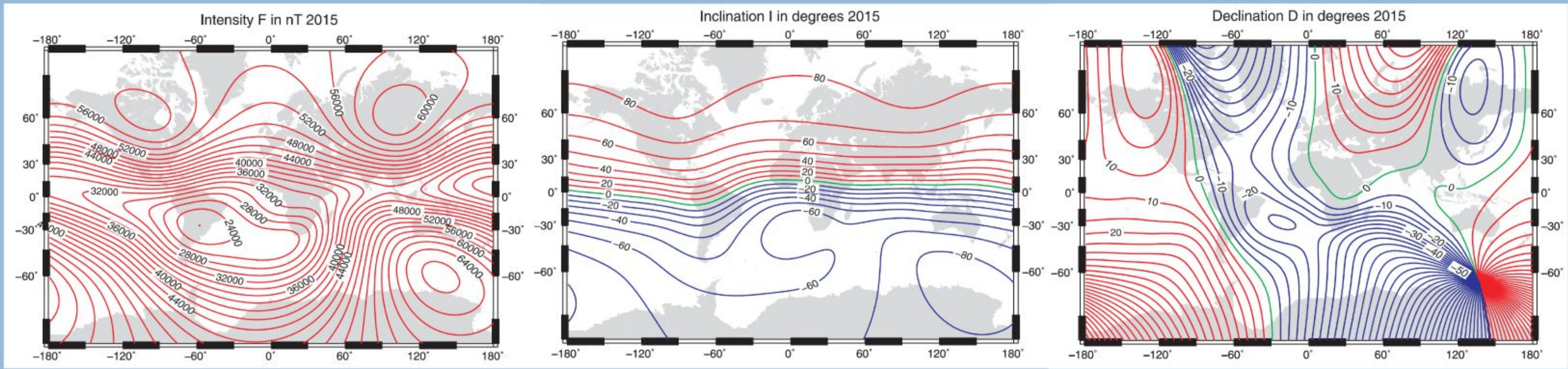


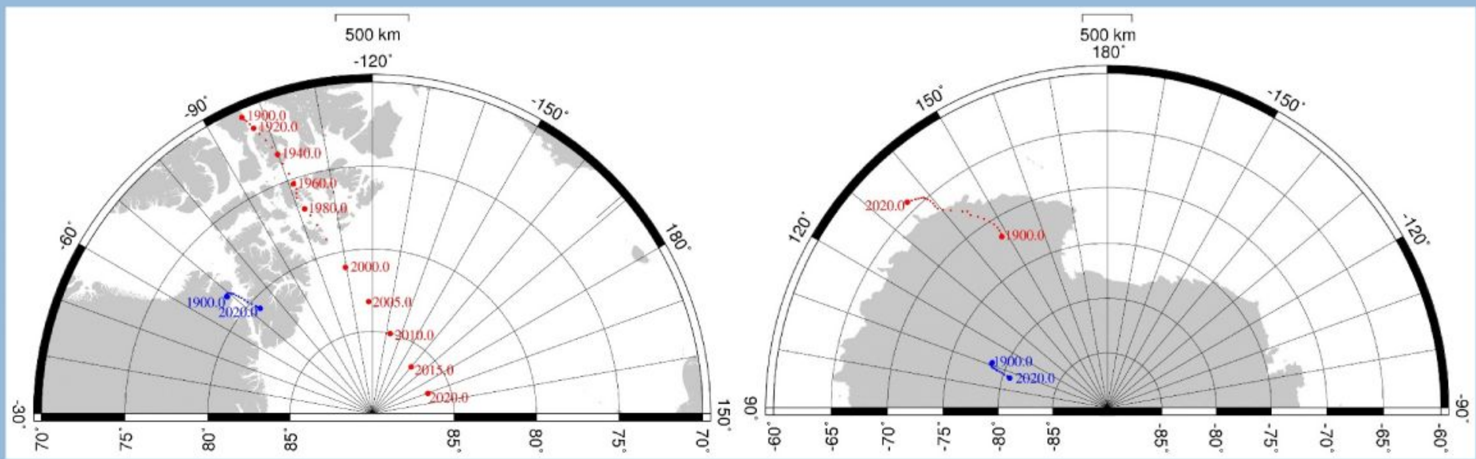
GEOMAGNETIC OBSERVATORIES IN THE WORLD



Spatial morphology of the Earth’s magnetic field

Components of the Earth's magnetic field at the surface from the IGRF model (12^{th} generation) for 2015



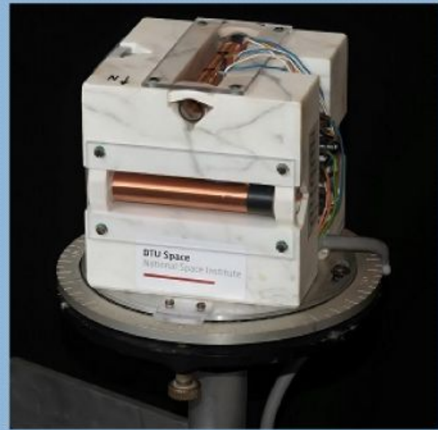


EARTH'S MAGNETIC FIELD TIME VARIATIONS AND RELATED INFORMATION

		DENOMINATION	SOURCE LOCATION	MAXIMUM INTENSITY	MORPHOLOGY	CHARACTERISTIC TIME	VARIATION ORIGIN	DETECTION
INTERNAL EARTH CONTRIBUTION		**MAIN FIELD**	**FLUID CORE** (1230- 3500 km from Earth's center)	**Average 45000-nT** (25000 to70000 nT**)**	**DIPOLAR + MULTIPOLAR**	Existing since **3.8 Gyears** POLARITY REVERSALS ($10^5 10^6$ YEARS) **SECULAR VARIATION** (T > 1-100/nT YEAR)	**ELECTRICAL CURRENTS AND (MHD) WAVES IN CONVECTIVE AND TURBOLENT REGIME IN THE FLUID CORE**	**SURVEYS** (GEOMAGNETIC OBSERVATORIES, SHIPS AEROMOBILE AND SATELLITE SURVEYS) ROCK MAGNETISM
INTERNAL EARTH CONTRIBUTION		**LOCAL FIELD**	**EARTH'S CRUST** down to Curie point temeperature depths	**200 nT** (AVERAGE WITH MAXIMA AROUND 10^4 nT)	Mainly locally dipolar and **IRREGULAR** (down to scales of a few m)	**Oldest magnetized rocks 3.8 Gyears Stable on Geological time scale**	**Ferromagnetic minerals and magnetic induction in the crust**	**LOCAL SURVEYS** SHIP AEROMOBILE AND SATELLITE SURVEYS) ROCK MAGNETISM
EXTERNAL EARTH CONTRIBUTION	IRREGULAR TIME VARIATIONS	**MAGNETIC STORM**	**MAGNETOSPHERIC CURRENTS**	**Dst 100-200 nT** (500 nT max)	**FIELD UNIFORM ON A GLOBAL SCALE, LATITUDE DEPENDENT**	**FROM 4 TO 12 HOURS; RECOVERY PHASE GOES FROM 1 TO 3 DAYS**	**SOLAR WIND INTERACTION WITH MAGNETOSPH. AND IONOSPHERIC PLASMA**	
EXTERNAL EARTH CONTRIBUTION	IRREGULAR TIME VARIATIONS	**SUBSTORMS (BAYS AT MID LATITUDES)**	**IONOSPHERIC AND FIELD ALIGNED ELECTRIC CURRENTS**	**100 nT** (200 nT IN AURORAL ZONE	**UNIFORM ON A LOCAL SCALE STRONGLY LATITUDE DEPENDENT**	**5 TO 100 MINUTES**	**SOLAR WIND INTERACTION WITH MAGNETOSPH. AND IONOSPHERIC PLASMA**	**GEOMAGNETIC OBSERVATORY MAGNETOGRAMS, TEMPORARY STATIONS AND SATELLITES**
EXTERNAL EARTH CONTRIBUTION	IRREGULAR TIME VARIATIONS	**PULSATIONS Continuous/Irregular**	**MHD MAGNETOSPHERIC WAVES AND CURRENTS FIELD LINE OSCILLATIONS**	**Few nT** (max100 nT in AURORAL ZONE	**ALMOST UNIFORM FILD, MORE INTENSE IN AURORAL ZONES Quasi periodic**	**Pc1: 0.2-5 sec Pc2: 5-10 sec Pc3: 10-45 sec Pc4: 45-150 sec Pc5: 150-600 sec Pi1: 1-40 sec Pi2: 40-150 sec Pg : Giant Pulsations**	**FIELD LINES RESONANCE IN MAGNETOSPHERE**	
EXTERNAL EARTH CONTRIBUTION	REGULAR TIME VARIATIONS	**DIURNAL VARIATION**	**TIDAL IONOSPHERIC CURRENTS**	**50-100 nT** (200 nT in equatorial zone)	**UNIFORM FIELD MORE INTENSE IN EQUATORIAL ZONE**	**T = 24, 12, 8, 6 HOURS**		
EXTERNAL EARTH CONTRIBUTION	REGULAR TIME VARIATIONS	**SOLAR**	**PHOTOIONIZATION**	**10-50 nT**	**UNIFORM**	**STRONG SEASONAL AND SOLAR CICLE CONTROL**	**IONOSPHERIC TIDES**	**GEOMAGNETIC OBSERVATORY MAGNETOGRAMS,**
EXTERNAL EARTH CONTRIBUTION	REGULAR TIME VARIATIONS	**LUNAR**	**ATMOSPHERIC TIDES**	**2-5 nT**	**UNIFORM**	**T = 24h 50m LUNAR**		
INTERNAL EARTH SECONDARY CONTRIBUTION		**EM INDUCTION BY EXTERNAL TIME VARIATION**	**CONTINENTAL AND OCEANIC CRUST AND UPPER MANTLE**	**SMALLER AMPLITUDE THAN PRIMARY; MAINLY IN Z**	**UNIFORM WITH IRREGULAR MORPHOLOGY**	**SIMILAR TO EXTERNAL PRIMARY, PHASE SHIFTS**	**ELECTROMAGN. INDUCTION BY PRIMARY EXTERNAL TIME VARIATIONS**	**GEOMAGNETIC OBSERVATORY MAGNETOGRAMS, TEMPORARY STATIONS**

INSTRUMENTATION FOR SURVEY MEASUREMENTS

The most widely used **scalar magnetometer** (for accounting the magnitude of the field intensity) is based on **the proton precession effect**: a direct current flowing in a solenoid creates a strong magnetic field around a **hydrogen-rich fluid** (kerosene or decane, or even water), causing some of the protons to align themselves with that field. When the current is interrupted, the protons realign themselves with the ambient magnetic field: they **precess** at a frequency that is directly proportional to the magnetic field. This produces a weak rotating magnetic field, picked up by an inductor, amplified electronically, and fed to a digital frequency counter.



The most widely used **vector magnetometer** is the fluxgate magnetometer which consists of a small, **magnetically susceptible core wrapped by two coils of wire**. An alternating electric current is passed through one coil, driving the core through an alternating cycle of magnetic saturation. In a magnetically neutral background, the input and output currents match. However, **when the core is exposed to a background field, it is more easily saturated in alignment with that field and less easily saturated in opposition to it**. Hence the alternating magnetic field, and the induced output current, are out of step with the input current. The extent of such difference depends on the strength of the background magnetic field.

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Facilities

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  - Castello Tesino magnetic Observatory (TN)
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  - Gibilmanna magnetic station (PA)
  - L'Aquila magnetic station (AQ)
  - Lampedusa magnetic Observatory (AG)
  - *Magnetic Observatory at Concordia Station*
  - Magnetic Observatory at Mario Zucchelli Station
- Seafloor Multidisciplinary Observatories
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Cambia Lingua

Magnetic Observatory at Concordia Station

Latitude: 75° 06′ S, Longitude: 123° 21′ E - 3200 m a.s.l. (Antarctica)

Concordia Station is placed about 1.200 km away from the coast, in a region of the Antarctic continent known as Dome C where ice thickness exceeds 3.200 m. It is here that Italian and French people have built a permanent base intended to operate 12 months a year. Among the various scientific installations there is also a magnetic observatory whose management is shared by Italian and French people. The station is located in a special place: in fact it is inside the polar cap where magnetic field lines are open and directly connected to the interplanetary magnetic field. This offers a precious opportunity to study external phenomena at high latitudes.

Instruments

Total intensity F is measured by an Overhouser magnetometer, measurements of the elements D, H and Z are made by a suspended three-axial magnetometer. The theodolite used for absolute measurements has been designed to operate at the low temperatures reached on the Antarctic plateau.

Geographic Co-ordinate:	75° 06′ S	123° 21′ E
Geomagnetic Co-ordinate:	88° 47′ S	54° 50′ E
Elevation:	3200 m a.s.l.	

Corrected geomagnetic coordinates are estimated for the epoch 2007.0 by the routine available at the NASA CCMD website.

Data

- **Daily magnetograms**
- Digital archive

Contacts

- **Dr. Domenico Di Mauro**

Related Units

- **Geomagnetic Observatories and National Magnetic Network**

Themes

- **The Earth's Main Field** *Earth's Magnetic Field*
- **Internal origin time variations** *Earth's Magnetic Field*
- **External Origin Time Variations** *Earth's Magnetic Field*
- **Geomagnetic Indices** *Sun-Earth Relations: Geomagnetic Phenomena*
- **Magnetic Pulsations** *Sun-Earth Relations: Geomagnetic Phenomena*
- **Magnetic Activity** *Sun-Earth Relations: Geomagnetic Phenomena*

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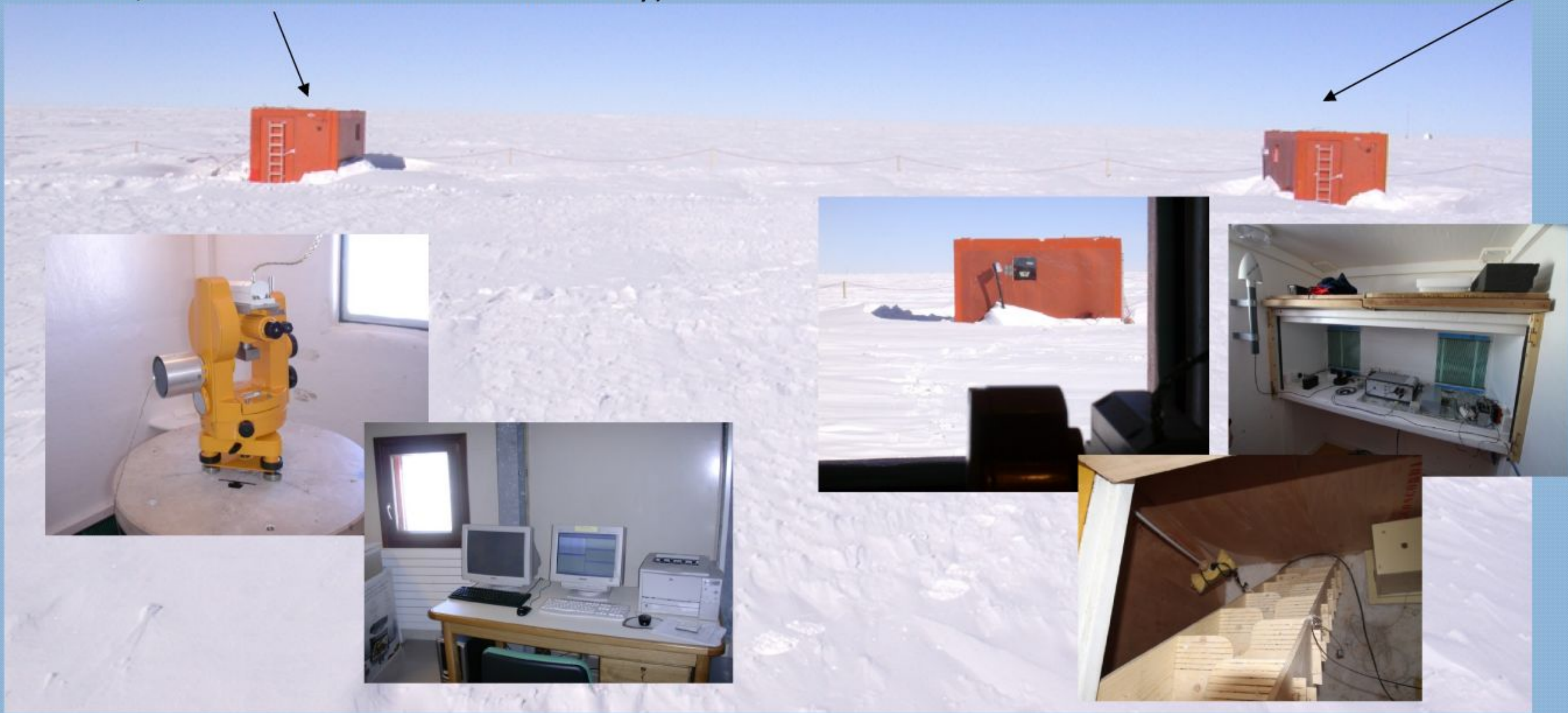
A geomagnetic observatory is a facility established far from anthropogenic disturbances, far from crustal magnetic anomalies (volcanic areas forbidden) where automatic recordings are collected and absolute measurents are routinely manually performed. All the material used must be amagnetic, the place topographically stable (incidental displacement or bent of the pillar or instability of the platform where instrumentations are installed must be avoided).

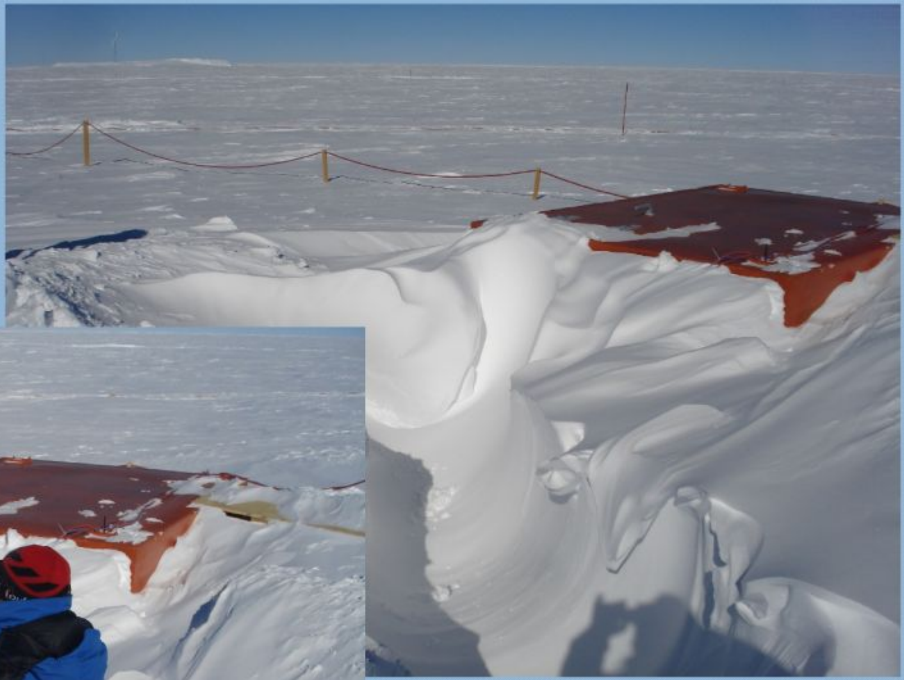
Shelter for absolute measurements
(Declination, Inclination and scalar F intensity)

Shelter for automatic recordings (X, Y and Z, additional scalar F intensity)

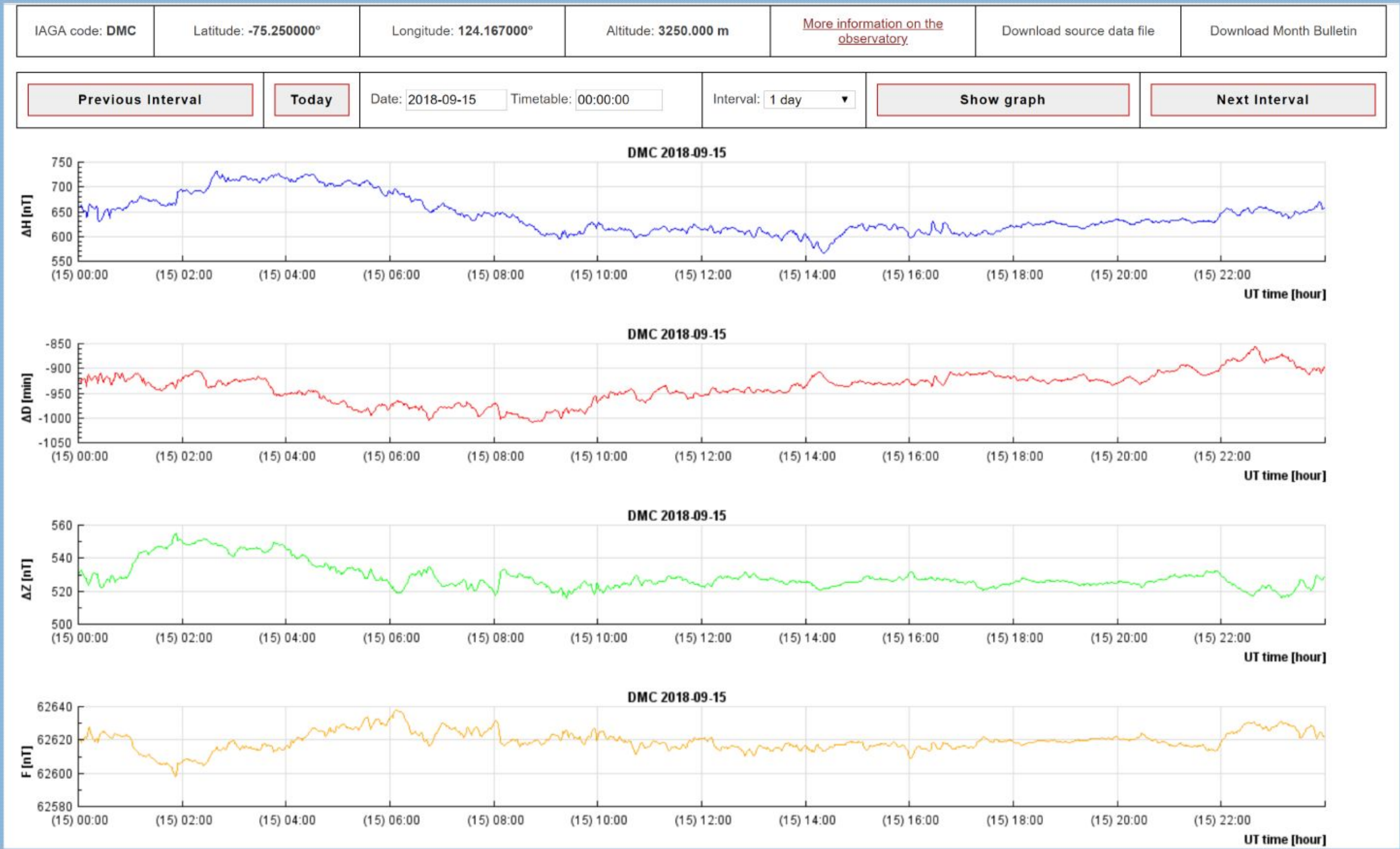


CONCORDIA Geomagnetic observatory, Italy and France, DOME C - Antarctica

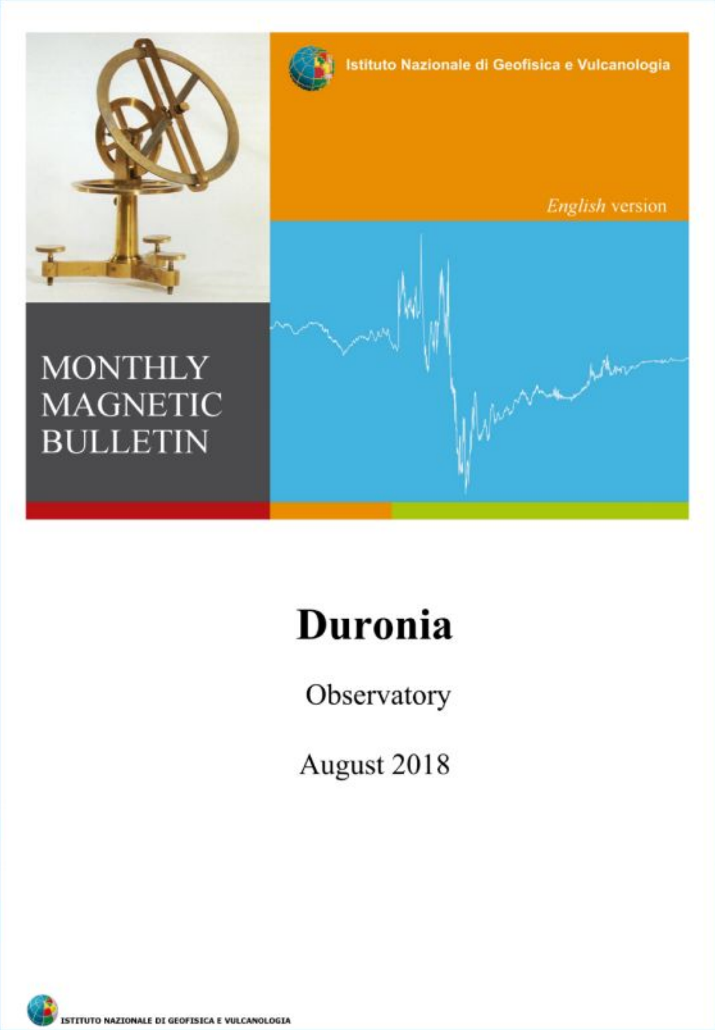
Difficulties from a pillar rooted on a floating basement (DMC, Concordia – Antarctica)

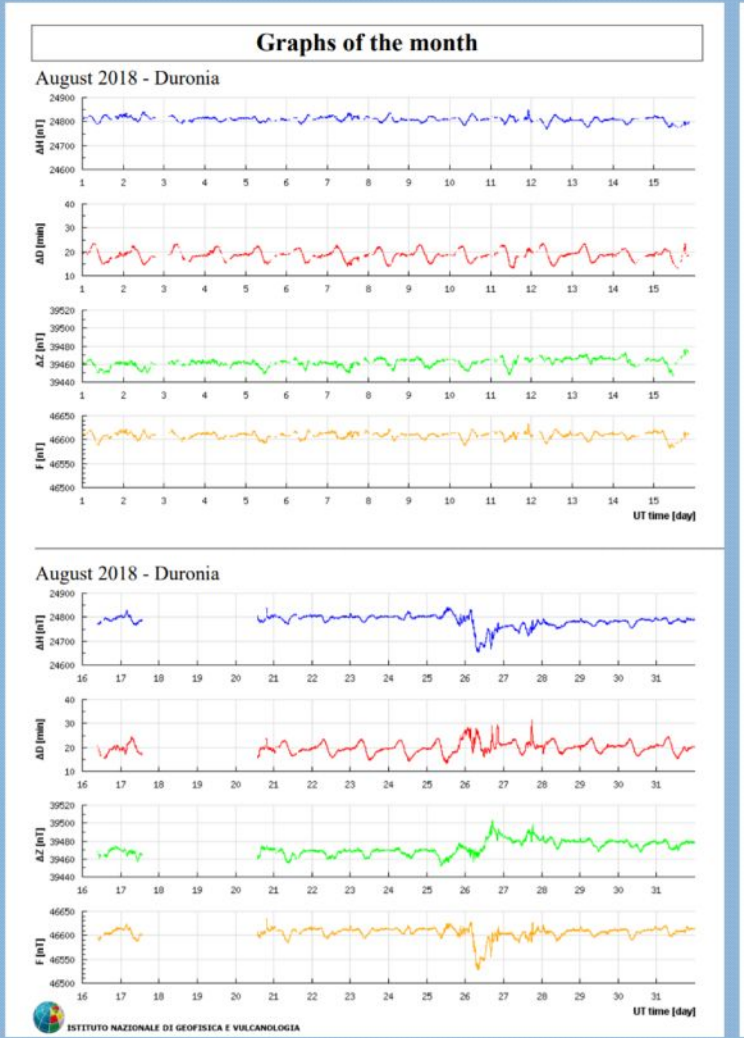


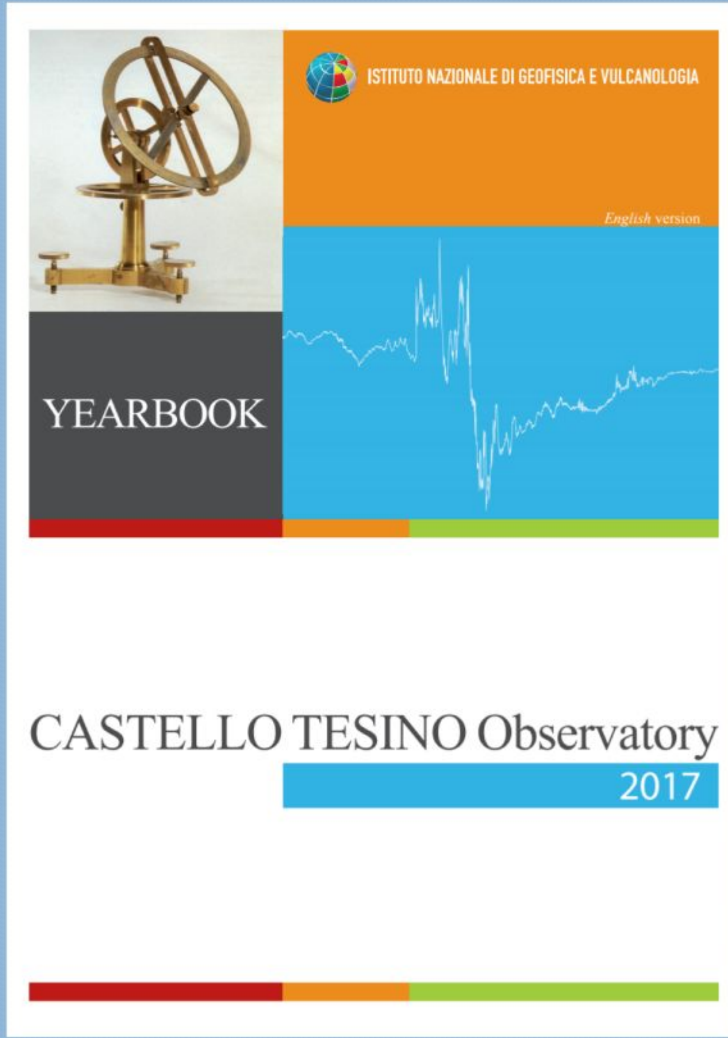
Product from a geomagnetic observatory (DMC, Concordia – Antarctica)



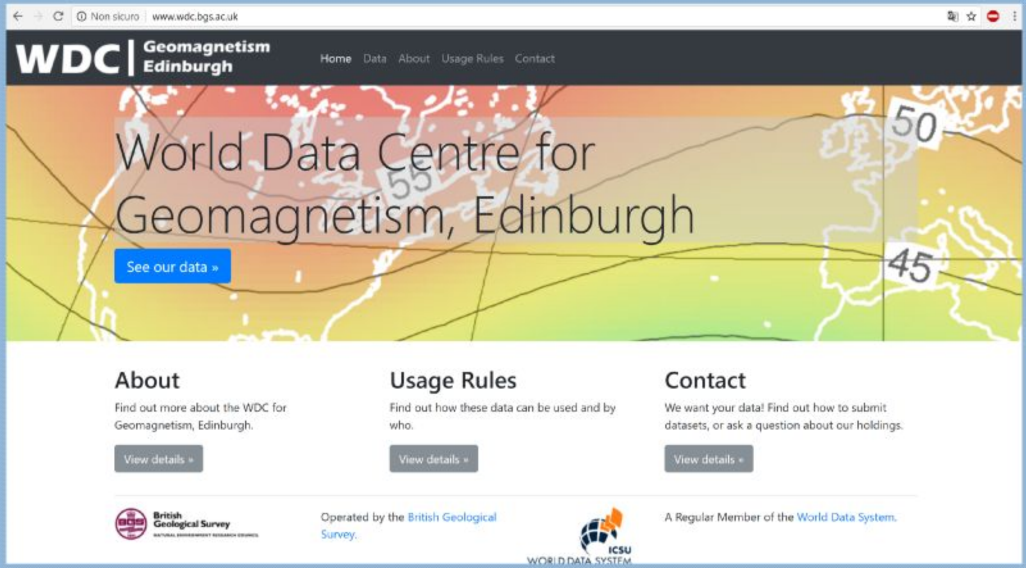
Product from a geomagnetic observatory (DUR, DURONIA and CTS, CASTELLO TESINO– Italy)

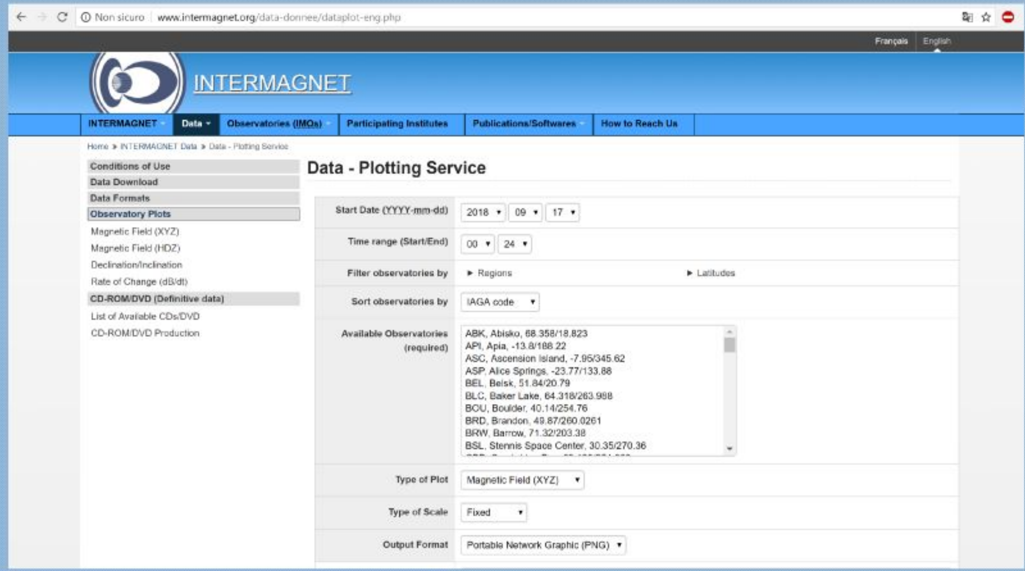


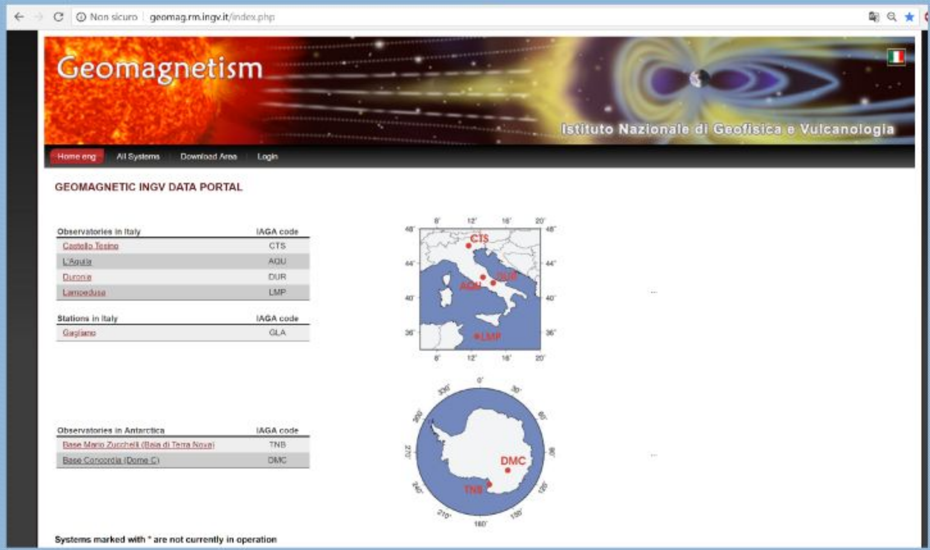




WHERE FIND DATA: LOCAL DATA PORTAL, WORLD DATA CENTERS, INTERMAGNET







www.wdc.bgs.ac.uk

www.intermagnet.org

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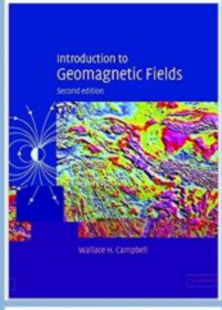
Useful references:

W. H. Campbell, *An Introduction to Geomagnetic Field*, Cambridge Univ. press, 352 pp, **ISBN:** 9780521529532



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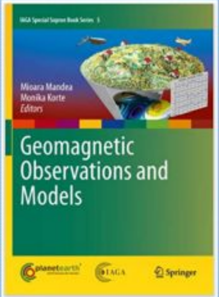

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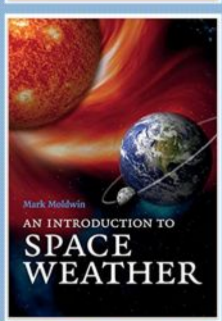

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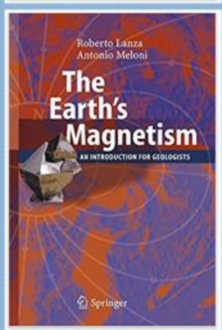

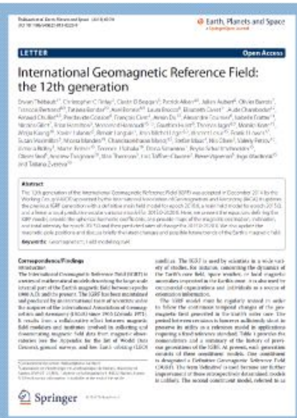
Earth, Planets and Space

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International Geomagnetic Reference Field: the 12th generation

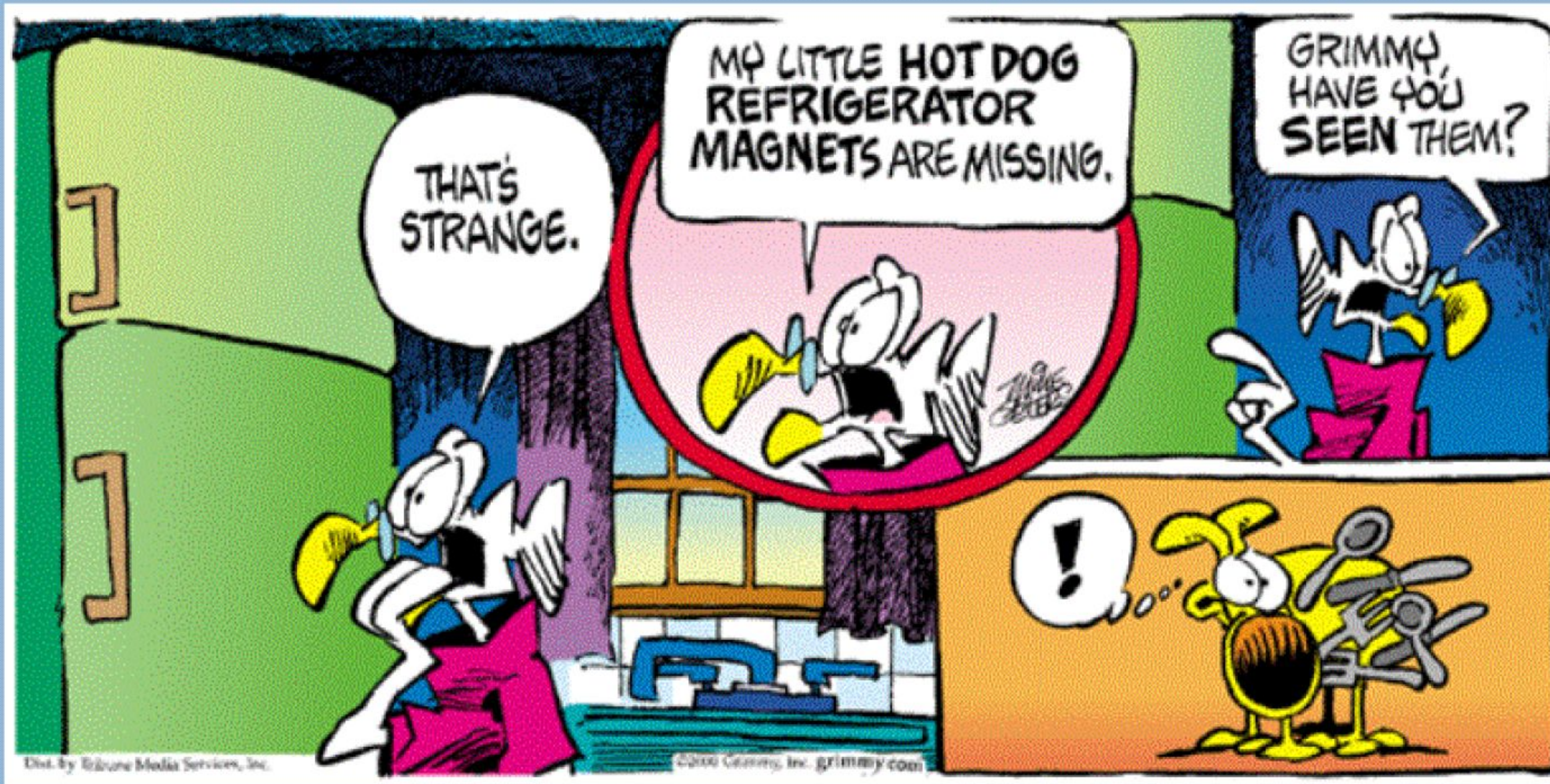
Springer

Thébault *et al. Earth, Planets and Space* (2015) 67:79, DOI 10.1186/s40623-015-0228-9


Geomagnetic polar observatories: the role of Concordia station at Dome C, Antarctica

Di Mauro *et al. Annals of Geophysics* (2014) 57 (6), DOI: //doi.org/10.4401/ag-6605

G. Dominici and A. Meloni, *Annals of Geophysics* (2014) 57 (6), DOI: , 60, 2, 2017, G0219, doi: 10.4401/ag-7062


THAT'S STRANGE.
MY LITTLE HOT DOG REFRIGERATOR MAGNETS ARE MISSING.
GRIMMY, HAVE YOU SEEN THEM?
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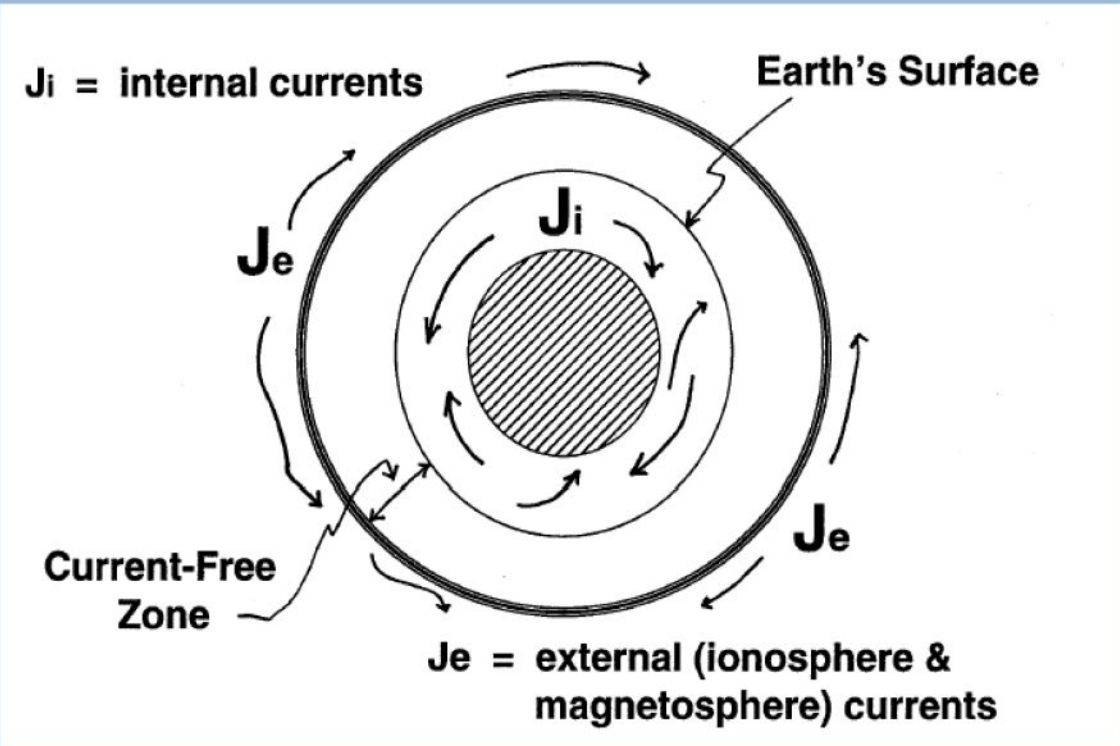
THANK YOU

Determination of the spherical harmonics for the magnetic scalar potential V, poles and multi-poles (Gauss, 1830)



The magnetic field at the surface of the earth is determined mostly by internal currents with some smaller contribution due to external currents flowing in the ionosphere and magnetosphere

In the current-free zone

$$\nabla \times \vec{B} = \frac{1}{\mu_o} J = 0$$

Therefore

$$\vec{B} = -\vec{\nabla} V$$

Combined with another Maxwell equation:

$$\vec{\nabla} \cdot \vec{B} = 0$$

we derive the Laplace's Equation

$$\nabla^2 V = 0$$

The magnetic scalar potential V can be written as a spherical harmonic expansion

$$V = a\sum_{n=1}^{\infty}\left(\left(\frac{r}{a}\right)^{n} T_n^{\mathrm{e}} + \left(\frac{a}{r}\right)^{n+1} T_n^{\mathrm{i}}\right)$$

The general expression of the magnetic potential is written by means of the function *Tn* with its indices i for internal and e for external, represented by the product of two angular parameters, latitude and longitude on the spherical geometry.

$$T_n = \sum_{m=0}^{n} (g_n^m \cos m\lambda + h_n^m \sin m\lambda) P_n^m(\theta)$$

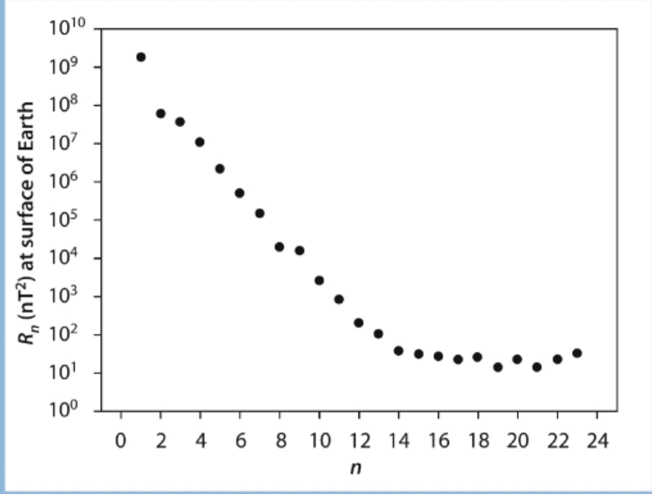
For each so-called spherical harmonic function *Tn*(θ, λ), *g* and *h* are the expansion coefficients for the magnetic potential, known as **Gauss coefficients**.

$$V = a\sum_{n=1}^{\infty}\sum_{m=0}^{n} \left(\frac{a}{r}\right)^{n+1} P_n^m(\theta)(g_n^m \cos m\lambda + h_n^m \sin m\lambda)$$

The potential function of the geomagnetic field can be completely formulated taking only into account the terms of internal origin.

When only internal sources are considered all contributions to the geomagnetic field, i.e. the sum of all Gauss coefficients up to a given degree *n*, can be shown on in a semi-logarithmic scale plot as a function of the order number *n.*

$$R_n = (n+1)\sum_{m=0}^{n}\left[(g_n^m)^2 + (h_n^m)^2\right]$$



Since 1839 to 2000, when Gauss firstly computed the coefficients the dipole magnetic moment (n = 1) has decreased from 9.6 × 10^{22} to 7.8 × 10^{22} $A \cdot m^2$