On the scientific contributions of Pierre Noël MAYAUD

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Abstract :

In this paper, after a short biography on Mayaud, we present his main scientific works on : the determination of the south magnetic pole in 1952, the polar magnetic activity, the day-to-day variability of the daily regular variation of the Earth's magnetic field S_R, the Sq equivalent current systems, the K, Kp, Km indices, the classification of the magnetic days, the constitution of the centennial series of aa index, the analysis of a centennial series of Sudden Storm Commencement, the equatorial electrojet and counter-electrojet more generally the study of all the transient variations of the Earth's magnetic field.

Introduction

This paper is devoted to Mayaud's scientific work. It is not an exhaustive presentation; we just recall some main results. However the bibliography is exhaustive.

Pierre-Noël Mayaud entered in the Company of Jesus in 1941 and was quickly oriented to geophysics research. Being in Antarctica from January 1951 to January 1952, he became Doctor es Sciences in Geophysics in 1955 and later senior scientist in CNRS (Centre National de la Recherche Scientifique) until 1978. He was awarded a silver medal of CNRS and received a price of the Sciences Academy. Now he is still working and we present his last publications at the end of this paper. The first section of this paper presents Mayaud's contributions on polar geophysics. The second section concerns his work on the daily solar regular variation of the Earth's magnetic field S_R and the mean variation of the Earth's magnetic field Sq. The third part highlights Mayaud's works on magnetic indices (mainly the Kp, Km and aa indices) and on the classification of international magnetic days and Sudden Storm Commencements (SSC). Part four is related to the counter-electrojet and finally in the conclusion we recall the publications made by Mayaud out of the scope of this paper.

1. Polar Geophysics

Figure 1 : South magnetic Pole in 1912

The figure 1 (Webb, 1912), on the right, shows the South magnetic Pole determined in 1912 by the Webb's team. They used dogs sledges to travel and their instruments were compasses for inclination and declination (actually inclinometer and declinometer). We notice on this figure the remarkable coherency of all the observations which constitutes for this epoch a document of an exceptional value.

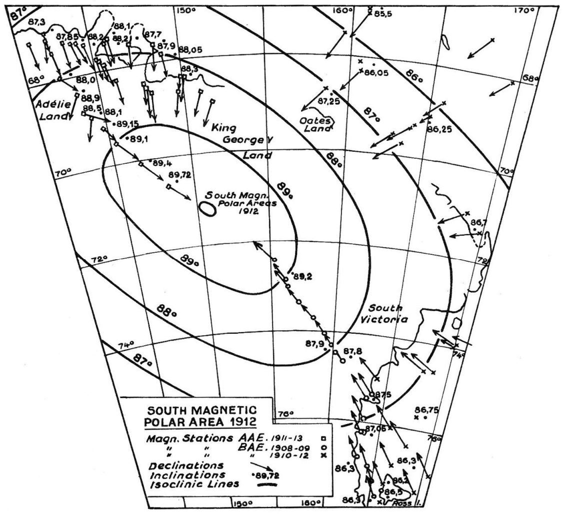
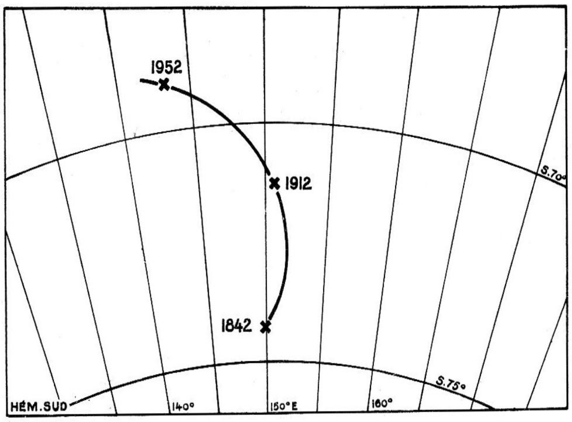


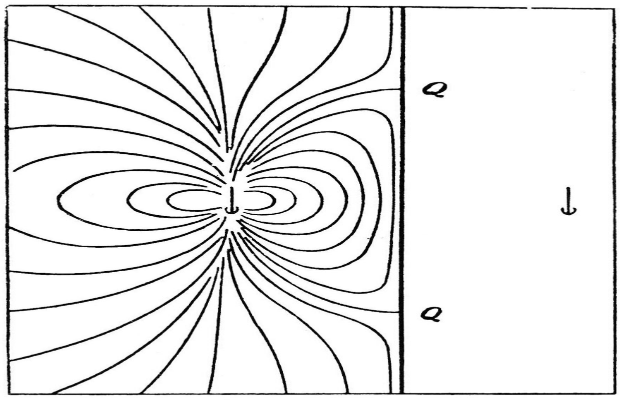
Figure 2 : South magnetic Pole in 1952



In 1951, Mayaud worked on the determination of the position of the South magnetic Pole (Mayaud, 1953a,1953b). Figure 2, on the left, illustrates his result. Mayaud used the sole secular variation of the Earth's magnetic field measured at Cape Denison. By rotation and displacement of the isoclines (curves of equal magnetic field inclination) he determined the position of the South magnetic Pole. **This "acrobatic" method revealed later valid compared with later independent determination of the South Pole.**

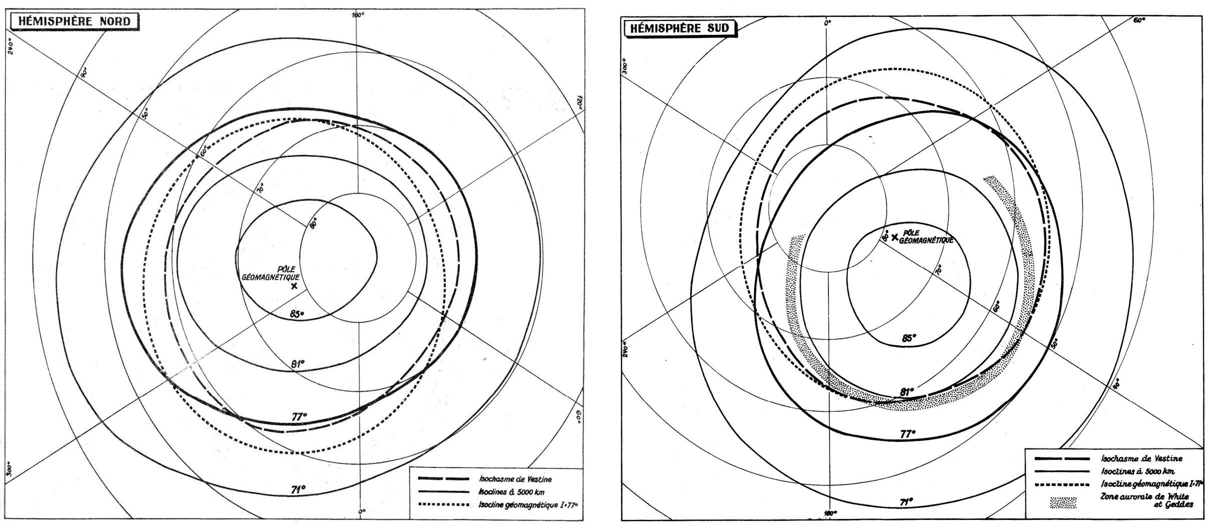
Mayaud's work (Mayaud, 1953c, 1953d, 1954a, 1954b, 1955, 1956) was the first analysis of the whole magnetic activity in the polar region**. His interpretation of the magnetic activity dayside polar cap by using the "horns" (Chapman and Ferraro, 1931) was a precursor of the discovery of the cusps by satellites.**

On figure 3 from Chapman and Ferraro (1931), is shown how the ionized plasma (on the right) distorts the Earth’s magnetic field, leaving only access for the particules to two particular polar regions called first the “ Horns” and later the “Cusps”.



In 1955, Mayaud showed also that the dipole coordinates do not allow a good localization of the magnetic phenomena in their diversity particularly in the polar zone. **He used the isoclines of the real magnetic field determined at the altitude of 5000 km** (Mayaud, 1958b, 1960). This was a rough shape of the corrected magnetic coordinates (CMC) introduced later. Figure 4 from Mayaud (1955b) shows various curves : the isoclines at 5000 km (full line), the isochasms of Vestine, curves of equal frequency of aurorae (dashed line), and the isoclines of the dipole (dotted line). The left panel is for the northern hemisphere and the right panel for the southern one.

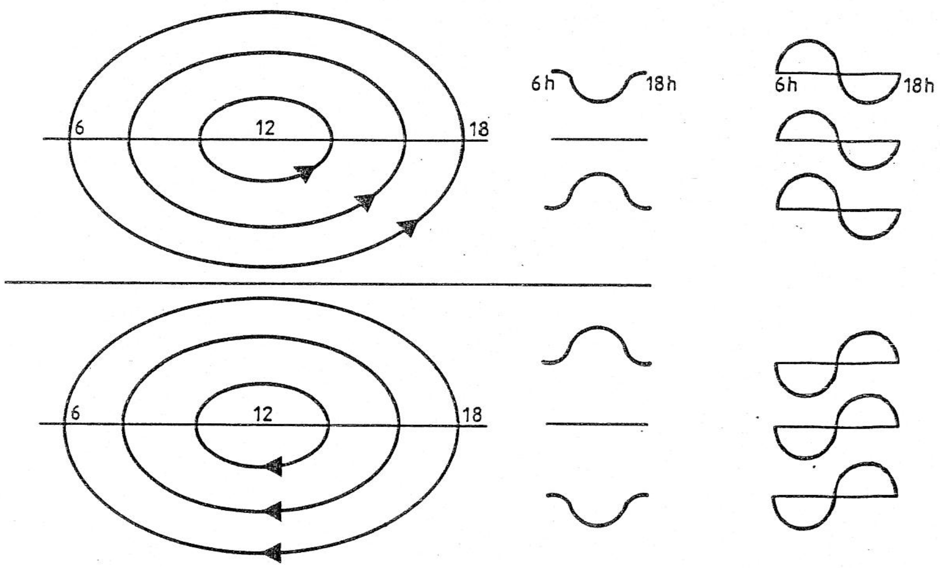
Figure 4 : Different magnetic coordinate systems



2. Solar regular variation of the Earth’s magnetic field S_R and Sq

Figure 5 represents the equivalent Sq current system. This is an idealistic representation of the Sq current system derived from the observations of the H and D components of the Earth’s magnetic field, by using the approximation of a plane infinite horizontal layer for the ionosphere where the electric currents are circulating . This is a two dimensional picture assuming the closure of ionospheric electric currents in each hemisphere and no parallel currents between the hemispheres. On the right side of this figure are drawn the H and D variations of the Earth' magnetic field seen by one observer during the day and in various places (at the focus, below and above the focus of each cell in each hemisphere). At the equator the model of a ribbon of equivalent electric current (not shown on this figure) is used to interpret the observations as we shall discuss later.

Figure 5 : Idealistic equivalent current system Sq from Amory-Mazaudier, 1983



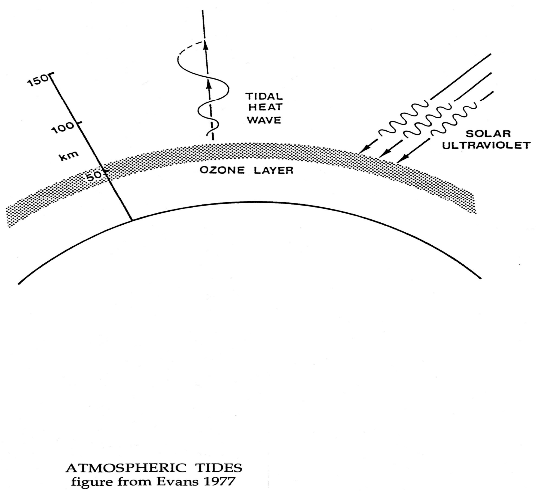


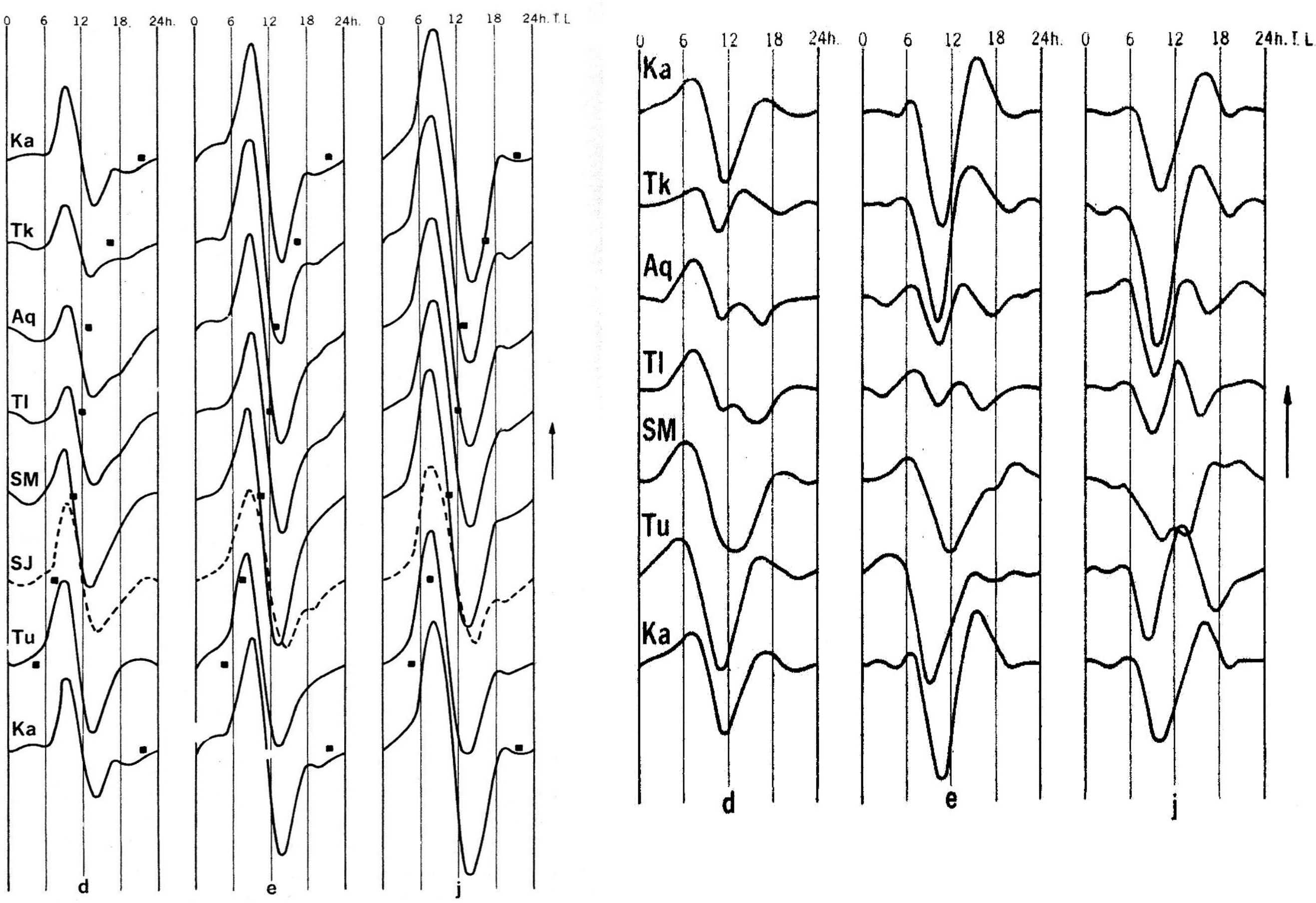
Figure 6 : Atmospheric tides

Stewart (1882) first proposed that atmospheric motions are the source of the ionospheric electric currents which causes the regular variations of the Earth's magnetic field. Later, atmospheric tides were measured. Figure 6, from Evans (1977), illustrates the generation of atmospheric tides by the solar radiations.

Mayaud (Mayaud, 1963a, 1965c, 1965d, 1976c, 1979b, 1980c) started the study of the S_R when computing the Kp indices for the period 1933 to 1939, he discovered that the K indices were badly scaled at some stations. This work led him to **the analysis of the day-to-day variability of the S_R** in many stations. The S_R is the daily regular variation of the Earth's magnetic field for one individual day in one individual station. Mayaud showed that the S_R has two components, the Cm (mid-latitude currents) and the Cp (polar currents). The Cp is particularly strong in summer when the solar EUV and UV radiations are illuminating during the whole day the polar region. **Mayaud insisted on the fact that the day-to-day variability of the S_R is essential to determine K indices** as we will show later.

Mayaud (Mayaud, 1965a, 1965b) analysed also the Sq (mean variations of the Earth's magnetic field). On figure 7 (Mayaud, 1965d) are presented the Sq variations of the Y (left panel) and X (right panel) components of the Earth's magnetic field for the three seasons (December solstice -d, Equinox-e, and June solstice -j) averaged over three years 1958, 1959, 1960 and for several stations.

Figure 7 : Sq variations of the Y (D) and X (H) components

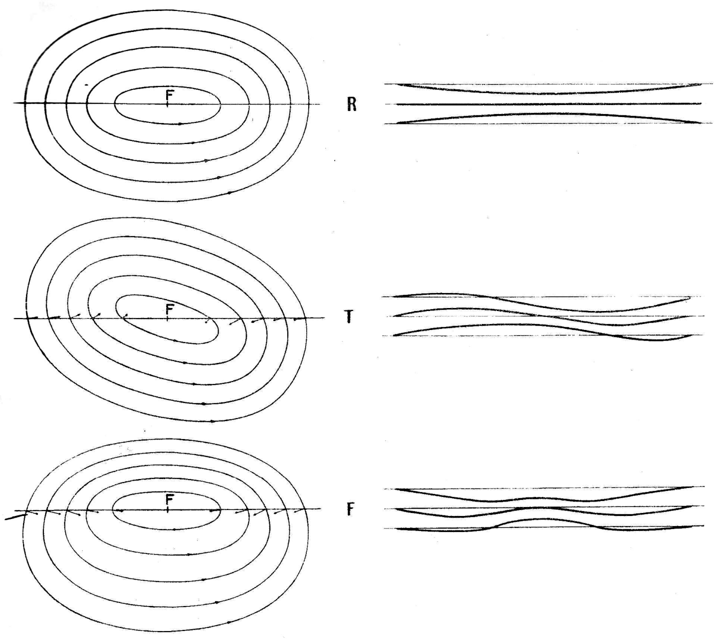


We must recall here that the Y component is comparable to the D component and the X component to the H one.

These curves do not exhibit the idealistic pattern of Sq of figure 5. We can notice morning and evening maxima on the X component (right panel).

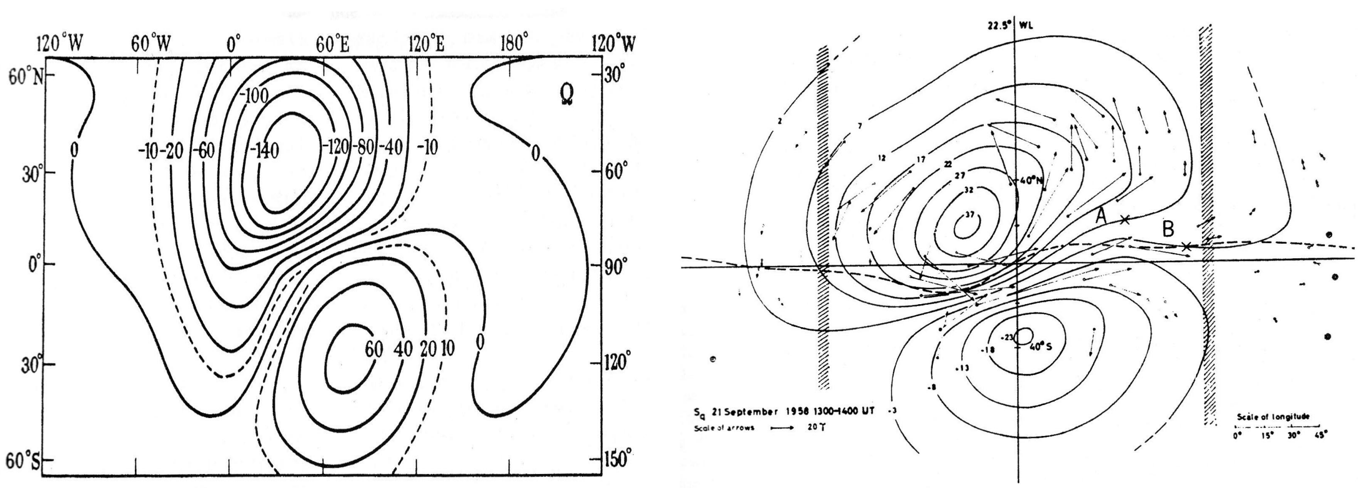
To better reproduce the observations Mayaud (1965d) proposed to keep the picture of the **equivalent current system with tilts, deformations and displacements.** This is illustrated on figure 8.

Figure 8 : proposed equivalent current systems



An other concept proposed by Mayaud (Mayaud, 1965d) to understand the observations was the **concept of "invasion" from one hemisphere to the other**. Figure 9 illustrates this concept according to the two equivalent current systems from Price and Wilkins (1963) on the left panel and Van Sabben (1964) on the right panel are drawn.

Figure 9 : " Invasion" from one hemisphere to the other



Price and Wilkins equivalent current system

Van Sabben equivalent current system

3. Magnetic indices, classification of international magnetic days and SSC

As we mentioned earlier, Mayaud started the study of the day-to-day variability of the S_R when he had to compute the Kp index for the international community, in order to complete the series of Kp for the years 1933 to 1939, between the polar international year and the beginning of the computation of the Kp index in 1939 (Mayaud, 1965e). **Mayaud spotted many errors in the scaling of the K indices** (Mayaud, 1961a, 1961b, 1963c, 1964a) **due to the ignorance of the day-to-day variability of the S_R.**

Magnetic K, Kp and Km indices :

In each magnetic observatory the K indices are deduced from the range, during a three hour interval, of the deviation of the observed horizontal components with respect to the Solar Regular S_R variation of the day.

The difficulty in scaling the K-indices lies in:

- **the identification of the S_R**
- **the determination of the ZERO LEVEL, taking into account the influence of the ring current (Dst)**

Figure 10 : H component of the Guam observatory

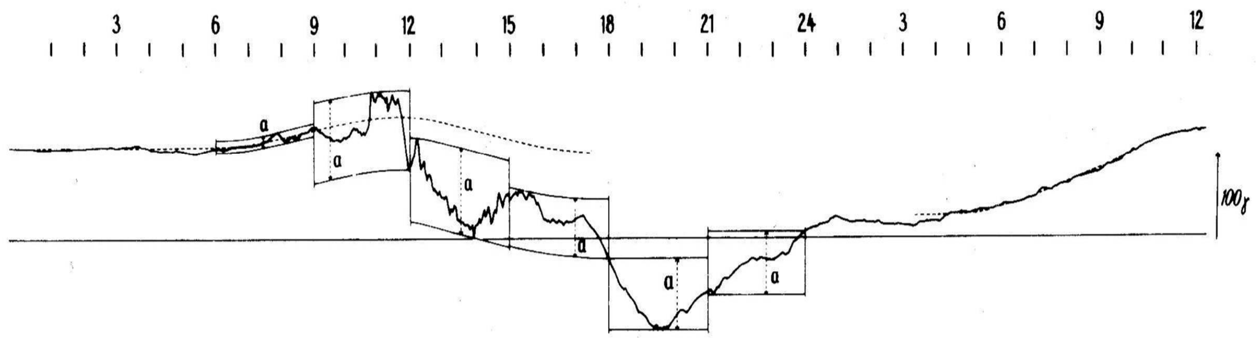


Figure 10 (Mayaud,1967a) represents the H component of the Earth's magnetic field at Guam (full line) and the S_R (dashed line) . This figure illustrates the precariousness of the H measurements in a low latitude station.

In each observatory, the gammas deviation are transformed by using a scale table in a value between 0 and 9 to obtain the K-indices. The scale table depends on the observatory latitude.

By taking the K-indices scaled in different observatories, one deduced different indices. The Kp index is based on the K-indices of 11 observatories. There is only one observatory in the southern hemisphere and these observatories are not representative of all longitude sectors .

Therefore the Kp index is not a planetary index.

That is why Mayaud proposed the Km index, where m means: mondial (worldwide) (Mayaud, 1967b, 1968, 1979a, 1980b). This index is based on the K-indices from 24 sub-auroral stations, 15 in the northern hemisphere and 9 in the southern hemisphere. These observatories cover all the longitude sectors.

Therefore the Km index is a planetary index.

The Km index has two components: Kn for the northern hemisphere and Ks for the southern hemisphere. Mayaud (1970 a, 1970b) analysed a series of 9 years of Kn and Ks indices and found that the magnetic activity is 10% higher in the northern hemisphere than in the southern one. **The asymmetry between the two hemispheres is now the subject of many scientific studies with the satellite measurement facilities. It is therefore important to use the Km index which take into account the two hemispheres.**

In 1978 during a worldwide travel in (80-1) days, Mayaud (Menvielle and Mayaud, 1980) visited all the magnetic observatories selected for the Km index in order to train the observers and to analyse the characteristics of each station. **For each station a sample of one year of K indices has been established as a reference.**

Mayaud (Mayaud,1980a) wrote a book for the international community to recapitulate the determination and the use of magnetic indices.

Classification of international magnetic days

The classification of days according to their magnetic activity level was introduced first in 1905, using the Ci index to select the five quietest days per month. Johnston (1943) proposed the method (still used) based on the use of the three-hours Kp indices, to select the five quietest days as well as the five most disturbed days.

Mayaud (Mayaud,1969) worked on the classification of the international magnetic days and reached to the following conclusions :**1) the value in gammas (am, ap) is better than index value for the classification of magnetic quiet days and 2) the classification of magnetic disturbed days is not significant due to the diversity of magnetic disturbances. He proposed to stop this classification**.

The five quietest days of a month are not necessarily quiet days, indeed if there is strong magnetic activity during the entire month, the five magnetically quietest days can be disturbed days.

The centennial series of aa index

One of the major works ok Mayaud (Mayaud, 1971a, 1972, 1973; Delouis and Mayaud, 1975; Mayaud 1975b, 1976a, 1976b, 1977c, Courtillot et al., 1977) was the constitution of the centennial series of the aa index. **This series is the sole centennial series made by one person, and as a consequence exhibits a good homogeneity**. This index is computed from the K indices of two antipodal magnetic observatories. This index was computed on the request of the Royal Astronomical Society of London to obtain geomagnetic index before 1884. At the beginning, Mayaud used Melbourne and Greenwich which were replaced later by Abinger and Hartland for Greenwich and Toolangui and Canberra for Melbourne. To constitute this exceptional series, Mayaud analysed 60 kilometers of magnetic records 5 cm by 5 cm.

On figure 11 from Mayaud (1972) the centennial series of aa index is plotted as a function of time. The curve is made up of running yearly averages with 12 points per year. We observe maxima and we will explain later how these peaks are related to the different magnetic solar cycles.

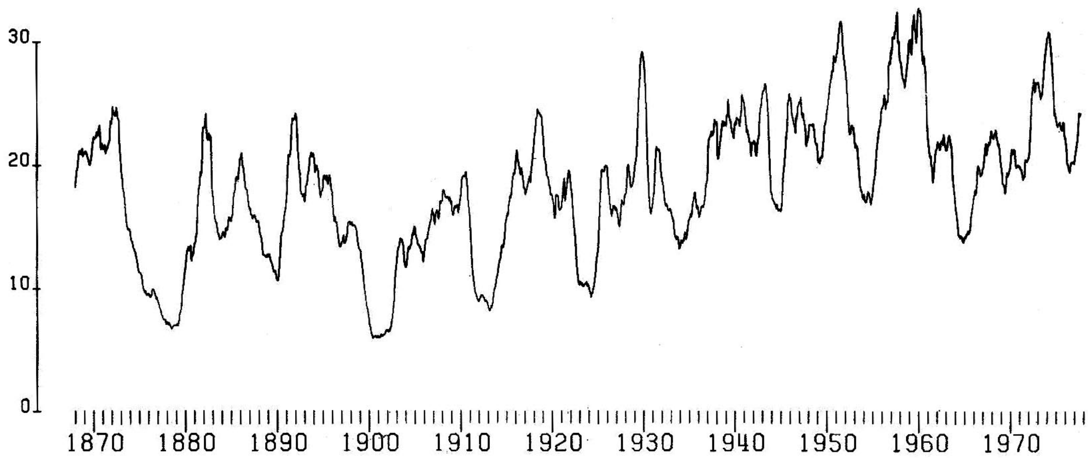


Figure 11 : Centennial series of aa index

The aa index was used by other researchers.

Legrand and Simon (1989) and Simon and Legrand (1989) analysed the centennial series of aa index in connection with the solar magnetic activity. On figure 12 from Legrand and Simon (1989) are plotted the centennial series of aa index (top curve) and the sunspot number (bottom curve).The aa index exhibits more maxima than the sunspot number. Legrand and Simon explained the dual peaks in the aa index as resulting from the different magnetic solar cycles. They showed that one maximum is related to the maximum of the dipolar solar cycle. This solar cycle controls the magnetic activity on 91.5% of the time, and reverses every 11 years.

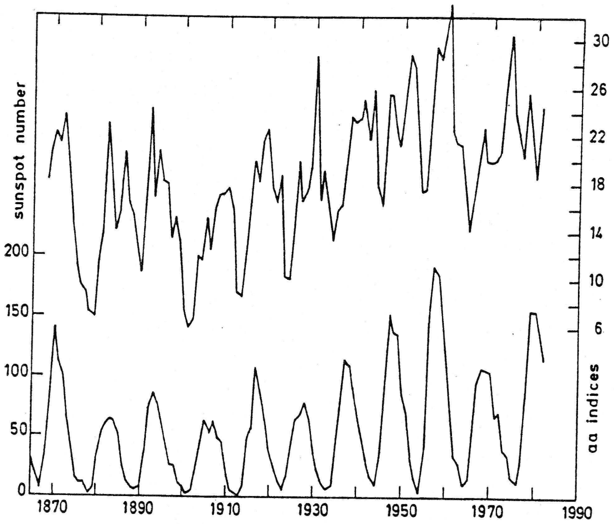
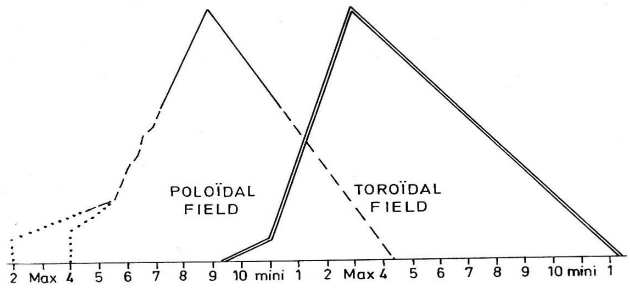


Figure 12 : aa index and sunspot number

At the time of the maximum of the solar dipolar magnetic field, high speed solar wind reach the Earth. The other maximum is related to the shock activity maximum which occur near the maximum of the toroïdal solar magnetic field well known as the sunspot cycle.

Figure 13 from Simon and Legrand (1989) illustrates the two solar cycles, the dipolar (called poloïdal on the figure) and the toroïdal solar magnetic fields.

Figure 13 : The two solar magnetic cycles



Legrand and Simon found that the intensities of these two solar magnetic cycles are closely related . The stronger the dipolar cycle, the stronger will be the following toroïdal solar cycle.

Figure 14 from H. Friedman (1986) illustrates the geometry of the two solar magnetic fields.

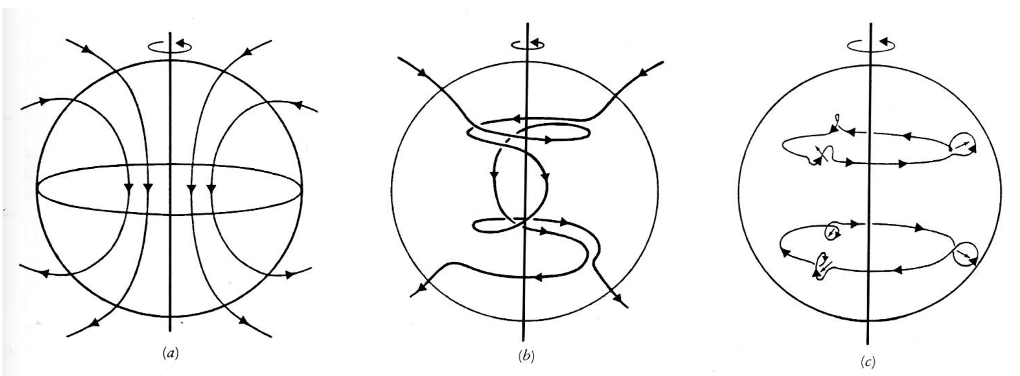


Figure 14 : Geometry of the solar magnetic fields

The results from Simon and Legrand show that the centennial series of aa index is really a good estimate of the solar activity. The aa index contains the signature of the two solar magnetic cycles.

Sudden Storm Commencements

Mayaud (Mayaud,1973, 1975a) analysed also a centennial series of Sudden Storm Commencements for the years 1868 to 1967. this series includes 2462 ssc. He found :

-That the negative correlation between the amplitude of ssc and rise time postulated by Dessler et al. (1960) is confirmed for the more rapid ssc (1-4 minutes),

-Yearly numbers of ssc are much better correlated with yearly averaged of sunspot numbers than with yearly averages of magnetic activity,

-The 27 day recurrence tendency is very small,

-There is no semi-annual variation of the occurrences,

-There is no daily variation of the occurrences,

-At subauroral latitudes , there is a daily variation of the amplitudes of ssc,

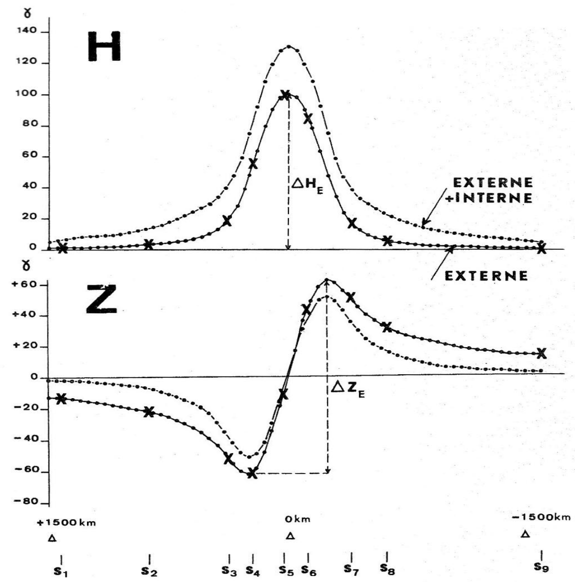
-The small seasonal dependence at low latitudes in the daily variation reported by Maeda et al. (1964) is confirmed

-There is a very large seasonal dependence at subauroral latitudes.

4. Equatorial Electojet and Counter-electrojet

Mayaud, Gouin and Fambitakoye on the equatorial electrojet and counter-electrojet (Mayaud, 1963b, 1967c; Gouin and Mayaud, 1967; Gouin and Mayaud, 1969; Mayaud, 1974b; Fambitakoye and Mayaud,1973, 1976a, 1976b, 1976c, Fambitakoye et al., 1976; Mayaud, 1977c)

Figure 15 from Fambitakoye (1973), on the right, shows the normal features of equatorial electrojet along a latitudinal chain crossing the magnetic equator.



The top panel corresponds to the H component and the bottom panel to the Z component. On each panel there are two curves, one for the total field (external + internal parts), and one for the sole external part of the magnetic field.The crosses indicate the location of the stations. The latitudinal profiles are computed by using the model of a ribbon of electric current circulating along the magnetic equator. The H component is maximum at the equator and decreases on the two sides of the magnetic equator. The Z component is minimum at the equator and exhibits two maxima on each side of the magnetic equator.

Gouin and Mayaud (Gouin and Mayaud, 1967) analyzed 8 years of magnetic data at Addis Abeba and characterized this phenomena. On figure 18 (from Gouin and Mayaud, 1967) are plotted for four different years (1958, 1961, 1964, 1965), the Sq of equinox, the SR of one individual day and the mean SR of three consecutive days. The counter-electrojet is observed during morning as well as afternoon hours (Gouin and Mayaud, 1969; Mayaud 1977c).

Figure 17 : Observations of counter-electrojet at Addis-Abeba

t. 23, fasc. 1, 1967] EXISTENCE D'UN CONTRE-ÉLECTROJET 3

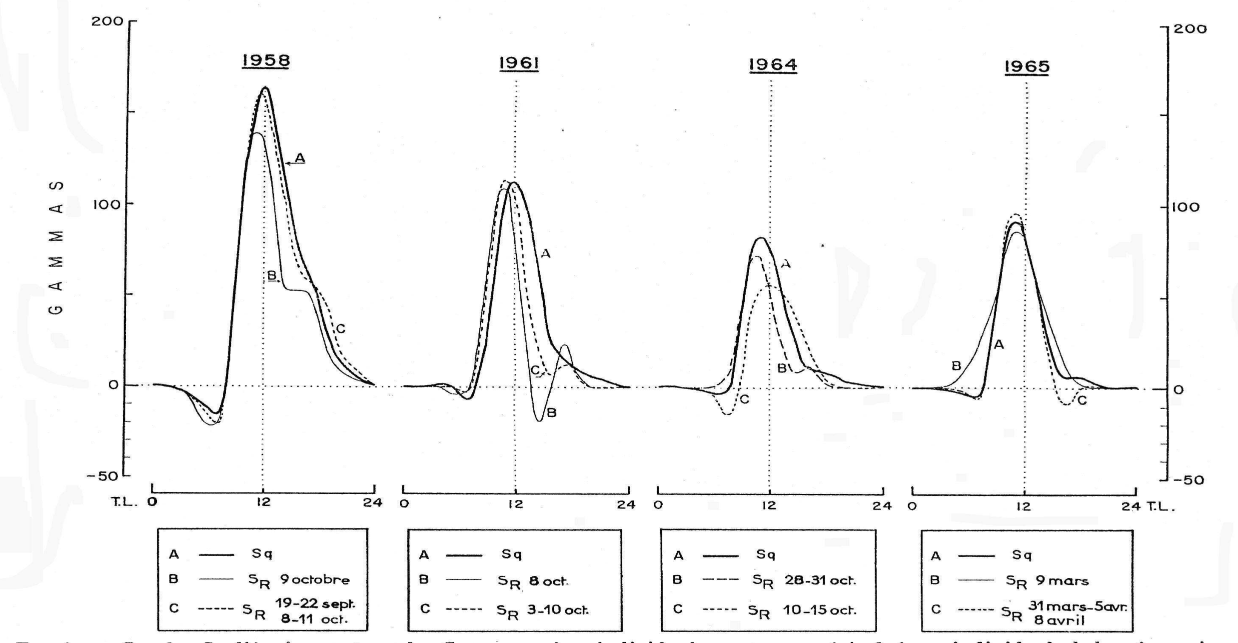
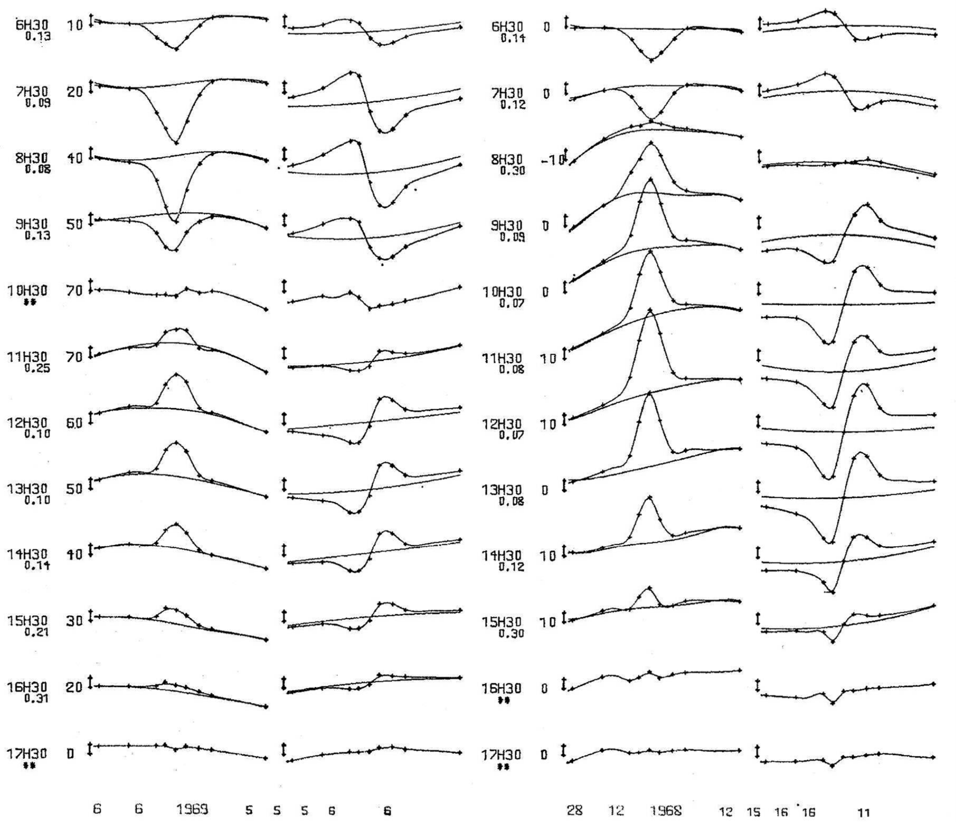


Fig. 1. — Courbes Sq d'équinoxe et courbes SR pour un jour individuel ou pour une série de jours individuels de la même saison de la composante H à Addis-Abeba, corrigées de la variation non-cyclique.

The definition of the counter-electrojet given by Gouin and Mayaud in 1967, corresponds to a reverse electrojet occurring during quiet magnetic days . **This phenomenon is not related to polar magnetic disturbances. One can observe reverse electrojet variations during magnetic disturbed, but these result from magnetic disturbances and are related to DP2 current system.**

On figure 18 are plotted the latitudinal profiles of the H and Z components of the Earth's magnetic field (Fambitakoye and Mayaud 1976c) over a latitude distance of 3000 km on June 6, 1969 (left panel) and December 28, 1968 (right panel). The curve associated to each latitudinal profile is the S_R without the amplification effect due to the equatorial electrojet. This figure shows a H component reversed to the normal in the morning hours. Similar results are also obtained for afternoon hours (Fambitakoye and Mayaud, 1976c)

Figure 18 : Latitudinal profile of the H and Z component



In a paper published in 1978, Mayaud described his knowledge concerning the transient variations of the Earth's magnetic field. In this paper Mayaud noticed the error he had made in 1955. As everybody at this time he tried to justify the Nikolsky's spiral (Figure 19). This spiral aimed at illustrating the latitudinal variation of the time of the activity maximum during daytime (Mayaud, 1978b).**This is an example of misinterpretation when the morphological features are neglected.**

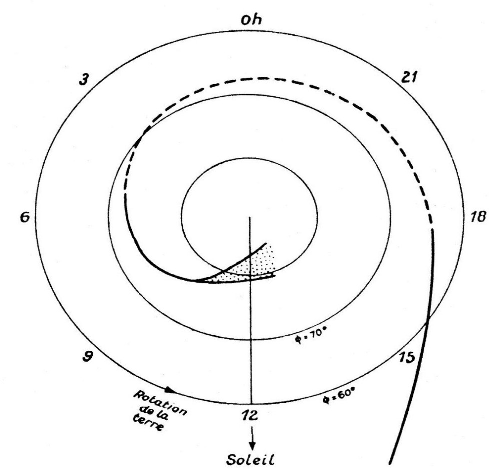


Figure 19 : Nikolsky's spiral

Conclusion

In this paper we presented the main scientific contributions of Mayaud :
•Determination of the South pole in 1952
•Analysis of the whole magnetic activity in polar region
•S_R day-to-day variability
•Sq and its difference to the ideal pattern
•K indices
•Computation of the Kp from 1933-1939
•Introduction of a new index Km
•Monography of all magnetic indices
•The centennial aa index series
•Analysis of SSC during one century
•The equatorial electrojet and the counter-electrojet

Mayaud worked also on
•Sodium emission in the Austral hemisphere (Mayaud and Robley, 1954)
•Use of the earth's magnetic field for study of cosmic ray or magnetic activity (Mayaud, 1958a)
•The McIntosh effect in the AE and Dst indices (Mayaud, 1971b)
•The prospective in equatorial Geophysics (Cain et al., 1973)
•The semi annual variation of the magnetic activity and solar wind (Mayaud 1974a, Mayaud et al., 1974)
•The Boller-Stolow mechanism and semi annual and daily McIntosh effects in geomagnetic activity (Mayaud 1977a)
•The use of Wolf-Number for estimating long-term periodicities (Mayaud, 1977b)
•The annual and daily variation of the Dst index (1978a)
•Artificial components in the equivalent linear amplitude geomagnetic indices (Mayaud et al., 1978)
•The ionospheric disturbance dynamo (Mayaud, 1982)
•CHAMP satellite data (Lemoüel et al, 2003)
•History of Geophysics (Mandea and Mayaud, 2004)

J-C. Farman concluded his book review on "Derivation, Meaning and Use of Geomagnetic indices" by P.N. Mayaud, by this sentence :

" The dedication of his monograph to the 'Observers' shows us once again where Mayaud's prime interest lay --- in the records. We may surely say from the use which he made of them that he himself was no mean observer. He would be well satisfied, I think, if his work lead others to look and look again at the records."

Mayaud's comment

" D'aucuns m'ont parfois reproché de ne pas faire de la physique mais de la "zoologie"! Personnellement, je ne crois pas aux théories sur les phénomènes qui n'existent pas, ou qui sont mal décrits. J'ai essayé de les décrire (ainsi en 1978, en ce qui concerne les variations irrégulières et où j'ai résumé mon expérience de celles-ci) et aussi non moins de servir la communauté internationale en lui donnant des outils de travail .»

« Some people criticized my ways of doing physics as too much inclined towards "zoology"! Personally I do not believe in theories about non existing phenomena or about poorly defined phenomena. I tried to describe (for instance in 1978 on irregular variations, where I emphasized my experience on them) and also to serve the international community with relevant working tools."

Epilogue

During the last 15 years, Mayaud worked on the "Conflict between the New Astronomy and Holy Scripture in the XVIth and XVIIth centuries" . He published this work in six books totalizing 3400 pages (Mayaud, 2005). He analysed more than 500 books from 320 different scientists and 90 exegesis writers. Mayaud noticed that there is only one woman Marie Cunitz . Here are some sentences of the conclusion of the book of Marie Cunitz illustrating the sacred character of Astronomy,

" Que l'ARBITRE SUPRÊME des mouvements, qui est leur MODERATEUR PERPETUEL, fasse que même pour nous et nos exercices Astronomiques, « les Cieux racontent Sa Gloire » et que « le FIRMAMENT annonce les œuvres des ses mains » (Ps 18/2) ….. J'achève sur ce vœu et sur tout vœu possible. A DIEU SEUL LA GLOIRE. »

« The SUPREME ARBITRATOR of motions, who is their PERPETUAL MODERATOR, may he, even for us and for our Astronomical exercises, make "The Heavens tell His Glory", and " the SKIES show the works of His hands." (Ps 18/12). … I conclude on this vow and on every possible vow. ONLY TO GOD, THE GLORY."

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