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NIGHT SKY AND LOW LATITUDE AURORAE IN A
MAGNETIC STORM PERIOD

by

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SUMMARY

Airglow measurements from Haute-Provence Observatory (one solar cycle) and from Tamanrasset (IGY) are analyzed by the technique of superimposed epochs in order to detect any systematic variation during magnetic storms with sudden commencement.

At middle latitudes the perturbations are characterized by the occurrence of optical auroral events, such as visible white aurorae, photometric red aurorae, stable auroral arcs:

These are treated separately and a list of events is given for 13 consecutive years.

Storm effects on night airglow are weak and characterized as follows:

Middle and low latitudes :

The A group (5577.02 bands & continuum) increases a few percent during the main phase. In addition, the green line shows a positive post-perturbation with a marked intensity increase 35 hours after the SSC.

The B-group (OH, Na) decreases by about 10 percent during the main phase.

The red line at 6300 OI behaves differently at the two stations.

At Tamnassaret the Northern intertropical arc weakens and sometimes disappears during the main phase. At Haute-Provence the red line intensity is somewhat increased during the storm. A recombination in the F-region can not explain this effect, which indicates that a weak stable auroral arc may be systematically present during the main phase of the magnetic storm.

* CIEL NOCTURNE ET AURORES DE BASSE ALTITUDE EN PERIODE D'ORAGE MAGNETIQUE

INTRODUCTION

The upper atmosphere of the Earth is luminescent in night as well as in daytime. On the one hand, one recognizes init auroral emissions, whose excitation is due to impacts of energetic particles, with spectrum characterized by the presence of atomic lines and molecular bands of fairly high potential (more than some ten ev). The variations of their intensity and occurrence are very important and are fairly well known in the vicinity of the so called auroral zones. On the other hand, the night sky glow extends over the entire globe. Photochemical reactions, linked with the recombination of the dissociated and ionized atmosphere in daytime, under the effect of solar electromagnetic radiation, are at its origin. The excitation potentials of the night airglow are of a few electron-volts. As important emissions, such as those of forbidden oxygen lines, are also excited in the aurora, both phenomena were for a long time confounded.

Various night airglow emissions are sensible indicators of the physico-chemical state of the atmosphere in the 70 - 300 km altitude range. Their variations in period of geomagnetic disturbance could not, so far, be ascertained. The observations in this field are more recent, less numerous and, a fortiori more discontinuous than the magnetic observations. The present paper has for object to fill this gap.

THE OBSERVATIONS

Systematic measurements of night airglow are pursued at the Haute-Provence Observatory (43°56'N, 05°43'E) since 1953. One of the instruments [Baillet, 1955] permits the observation of the principal radiations in the visible domain, parallelwise to the world axis and in the direction of the zenith; this device has now been functioning for more than one solar cycle without any modifications of its operational conditions. A nearly identical photometer, directly compared with that of Haute-Provence, was used in Tamanrasset (22°47'N 5°32' E) from May 1957 to February 1960 on the occasion of the IGY [Barbier, 1961]. The current study rests upon the measurements performed with this apparatus; they are due in quasi entirety to D. Barbier. The two stations in question will be referred to here as OHP and TAM.

We shall return to neither the method of calibration of measurements by way of star enumeration [D. Barbier, 1961 and 1962a], nor on the relations existing between radiations of same group and the decontamination procedures derived therefrom [D. Barbier, 1960a]. Except when indicated to the contrary, all the intensities are expressed in the number of Go-stars and also of those of the 10th stellar visual magnitude per square degree. Table 1 is a reminder of the coefficients that allow to express the results in normalized units (Megaquanta per second for a vertical column of 1 cm² or Rayleighs for monochromatic radiations, and in Rayleighs per 100 Å for extended radiations).

The study of the correlations between radiations allows us to restore the decontaminated intensity of principal radiations, by combination of the observed radiances through different filters. The respective decontamination formulas for each station are recalled in Tables 2 and 3.

SELECTION OF STORMS AND CRITERIA OF GEOMAGNETIC ACTIVITY

a) HAUTE-PROVENCE

A selection of magnetic storms, having occurred during the period from July 1953 to December 1964 was made on the basis of the following criteria:

a) The storm is preceded by a sudden commencement published in Bartel's "Lists of Preliminary SSC's".

b) The phase of the Moon during the storm is favorable to observations, including the age comprised between -5 and $+5$ days at time of SSC.

c) The storm is well isolated in time, the closest adjacent SSC being at least at 36 hours from the studied SSC.

d) The atmospheric conditions at the Haute-Provence Observatory have permitted to perform at least one full night of observations during the period ranging from 12 hours prior to 36 hours after the sudden commencement.

An aggregate of 53 storms with sudden commencement was thus retained. These storms (Table 4) are rather regularly distributed as a function of the season and of the hour of their sudden commencement (Fig.1). The regularity of this distribution is important so as to enable one to separate statistically the eventual effects in local time and UT (storm time).

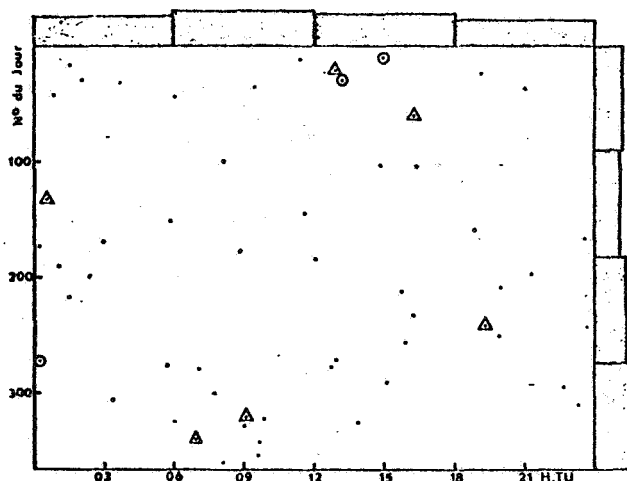


Fig.1. Distribution of the studied storms as a function of the hour and season. The histograms are per quarter and 6-hour period. Δ denotes a storm attended by an important enhancement of 6300 OI at OHP (aurora or red arc). $\odot$ denotes a storm accompanied by low-latitude white aurora observed at OHP. $\bullet$ indicates another storm.

In order to allow a detailed study of the relationships between the night sky light and the unfolding of the various phases of magnetic storms, a characteristic index had to be chosen for the geomagnetic variations. The ideal index should be representative of the global energy of the storm and calculated at least every hour, being available during the entirety of our period of observations. The Dst-index [Akasofu, Chapman, 1961, Sugiura, 1964] responded to the first of these criteria, but was published only for the duration of IGY and IGC. We just were led to utilize a local ΔH -index (Chambon-la Forêt Observatory), which was the difference between the horizontal component of the magnetic field, instantaneous at exact hours and the

T A B L E 1

Transformation coefficients of stellar units in Megaquanta $\text{sec}^{-1} \text{cm}^{-2}$
(Rayleighs)

	6700	6300 OI	6300 OII	5900	5577	5260	4400	3670	
	—	—	—	—	—	—	—	—	
Monochromatic line.		0,36		0,56	0,45			0,78	$\left\{ \begin{array}{l} 3582 \\ 3564 \text{ N}_2^+ \\ 3549 \end{array} \right.$ Rayleighs
Extended spectra ..	0,33		0,27			0,40	0,36	0,18	Rayl./100 Å

T A B L E 2

Decontamination formulas (OHP)

(1)	$I(6700, \text{OII})$	$= I(6700)$	$- 0,738 I(5260)$
(2)	$I(6300, \text{C} + \text{OII})$	$= I(6300, \text{OII})$	$- 0,818 I(5260)$
(3)	$I(5900, \text{Na} + \text{OII})$	$= I(5900)$	$- 0,779 I(5260)$
(4)	$I(5577, \text{OI})$	$= I(5577)$	$- 0,900 I(5260)$
(5)	$I(5260, \text{cont.})$	$= I(5260)$	$- 0,125 I(6700, \text{OII})$
(6)	$I(\text{N}_2^+)$	$= I(3670)$	$- 18,5 [I(5577, \text{OI})]^{0.53}$

T A B L E 3

Decontamination formulas (TAM)

(1)	$I(6700, \text{OH})$	$= I(6700)$	$- 0,460 I(5260)$
(2)	$I(5900, \text{Na} + \text{OII})$	$= I(5900)$	$- 1,13 I(5260)$
(3)	$I(5577, \text{OI})$	$= I(5577)$	$- 1,39 I(5260)$
(4)	$I(5577, \text{BA})$	$= I(5577)$	$- 0,166 I(6300, \text{OI})$
(5)	$I(\text{N}_2^+)$	$= I(3670)$	$- 7,95 [I(5577, \text{BA})]^{0.671}$

T A B L E 4

Year 1900	53	54	55	56	57	58	59	60	61	62	63	64
Number of observable storms.....	1	1		4	6	2	1	4	4	10	2	10
Number of observable red aurorae....					5		1			1	2	
Number of observable white aurorae..					3		1					

average monthly intensity for the same hour. By examining 4 storm periods of the IGY taken at different seasons, we could have assured ourselves that for the night hours, the only ones of interest to us, ΔH Chambon is very well correlated with the Dst computed by Sugiura (Fig.2).

To compare the optical and ionospheric effects, we have utilized the measurements of F_2 -layer's parameters by the De Bilt station ($52^\circ 06' N$, $5^\circ 10' E$) which is located on the same meridian as the OHP, but at 600 km to the North of the point where the line of photometer aiming crosses the F_2 - layer.

All the photometric registrations obtained by fair weather between 12 hours prior and 48 hours after every SC were taken down and measured at a pace of one cycle every 5 minutes. Each cycle is constituted of eight corresponding radiances to different filters and two calibrations, say a total of 10 quantities. The aggregate of these observations represents 9,010 cycles obtained in the course of 819 hours, spread over 133 nights of observation.

b) TAMANRASSET

The shortest period of observation at Tamanrasset had permitted to select only 18 storms according to the above criteria. The aggregate of measurements constitutes 3,531 cycles, 321 hours spread over 45 nights of observation. The storms are respectively 6, 6, 5 and 1 for the years 1957, 1958, 1959 and 1960. Their distribution is illustrated in Fig.3. Unfortunately, it is impossible to effect at Tamanrasset a detailed comparison of the night sky with the ionosphere, for the distance, separating the regions observed optically and radio-electrically is of the same order of magnitude as the width of an intertropical arc.

The Dst-index could be adopted to characterize the energy of the storm (cf. Fig.17) since it was published for the entire period analyzed, with the exception of the last storm.

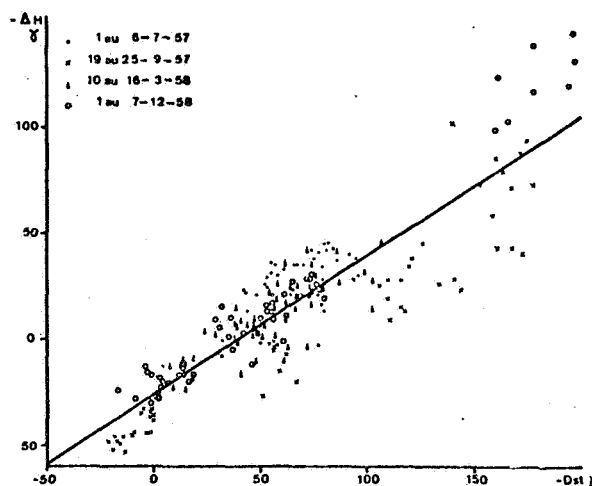


Fig.2. Correlation during night hours between the ΔH at Chambon-la-Forêt and Dst-index (Sugiura, 1964). Four IGY storm periods were chosen at different seasons to illustrate this correlation, which justifies the use of the Chambon ΔH as the characteristic index of magnetic storm energy.

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* * *

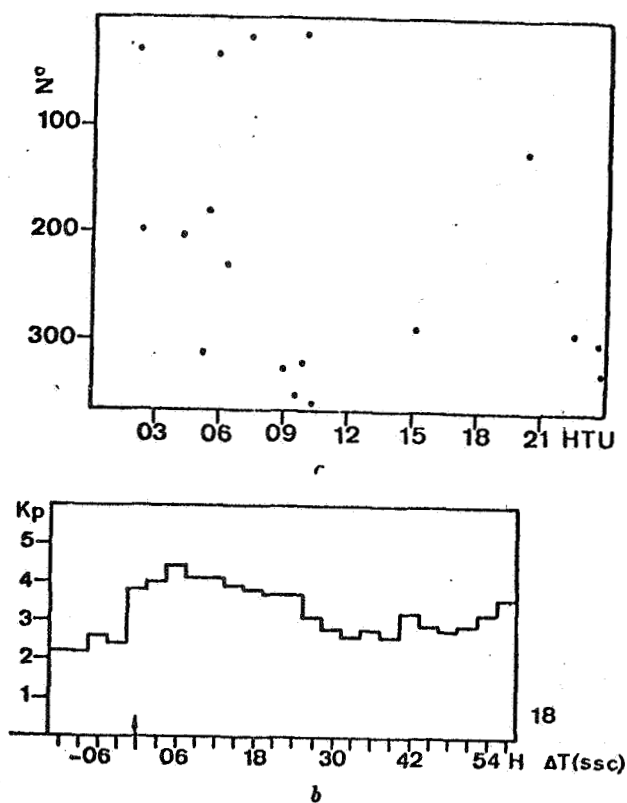


Fig.3. a) Distribution as a function of the hour and of the season in the course of which registrations were obtained at Tamanrasset
 b) Average of Kp-indices as a function of the time of the storm for the periods studied at Tamanrasset

ANALYSIS OF THE RESULTS

1. MID-LATITUDE AURORAE

Selection of Auroral Storms

A global statistical treatment of all measurements could only yield insignificant results; indeed, each filter transmits several radiations, every one of which possibly originating from different altitudes and excitation processes. Moreover, if the effect of magnetic storms on the night sky glow is apriori of the order of a few percent, certain radiations may be considerably enhanced in periods of low latitude aurorae: the intensities of red and green

lines of oxygen may be multiplied respectively by factors of 100 and 4 with respect to the mean level. Under these conditions the eventual variation of the night sky light would be in global analysis entirely concealed by polar aurorae.

It is established that aurora and night sky spectra correspond to very different excitation energies and to different emission processes. In order to separate the effects, we have grouped the measurements in three categories on the basis of optical criteria :

a) Periods of White Aurorae

These periods are characterized by the appearance with appreciable intensity of N_2^+ bands. The nonlinear correlation of measurements performed with 3670 and 5577 Å filters [D. Barbier, 1960a], excellent in normal periods, disappears in the presence of white aurorae, sunlit or not, on account of the contribution of the first negative system of ionized nitrogen. The remainder of the correlation (Table 2, formula 6) is characteristic of aurora appearance. All the periods in the course of which this residue exceeds the value of 60 (50 Rayleighs for the N_2^+ bands at 3582, 3564 and 3549 Å) were called "white aurorae". In the aggregate, they represent 50 hours of observation that do not permit a statistical treatment and must thus be dealt with separately.

b) Storms accompanied by Red Aurorae or Red Arcs

The middle latitude red aurorae and red arcs [D. Barbier, 1958] are very easily identified on the photometric registrations obtained in the direction of the pole, and more particularly around the horizon. Both these phenomena take place at high altitudes and affect essentially the intensity of the line 6300 Å. At any rate they are linked in the sense that the red arc is generally attendant of a red aurora of higher latitude. Out of the 53 storms, 9 were marked by their appearance and will be dealt with separately (excluding the periods of white aurorae).

c) Storms not attended by Major Optical Effects

The 44 periods of remaining magnetic storms in the course of which no particular event was directly apparent on the registrations, have been treated statistically so as to search for eventual low-amplitude variations that normally are missed during individual examinations of measurements. These storms represent 672 hours of registration, distributed over 110 nights.

The intensity variations during the nights, representative of each of these three categories, are reproduced in Figure 4. One may notice (Fig.5) that the above three categories correspond to storms of fairly different energy, the Kp-index maximum (average) for the three categories being 7.0, 7.0 and 4.8 respectively.

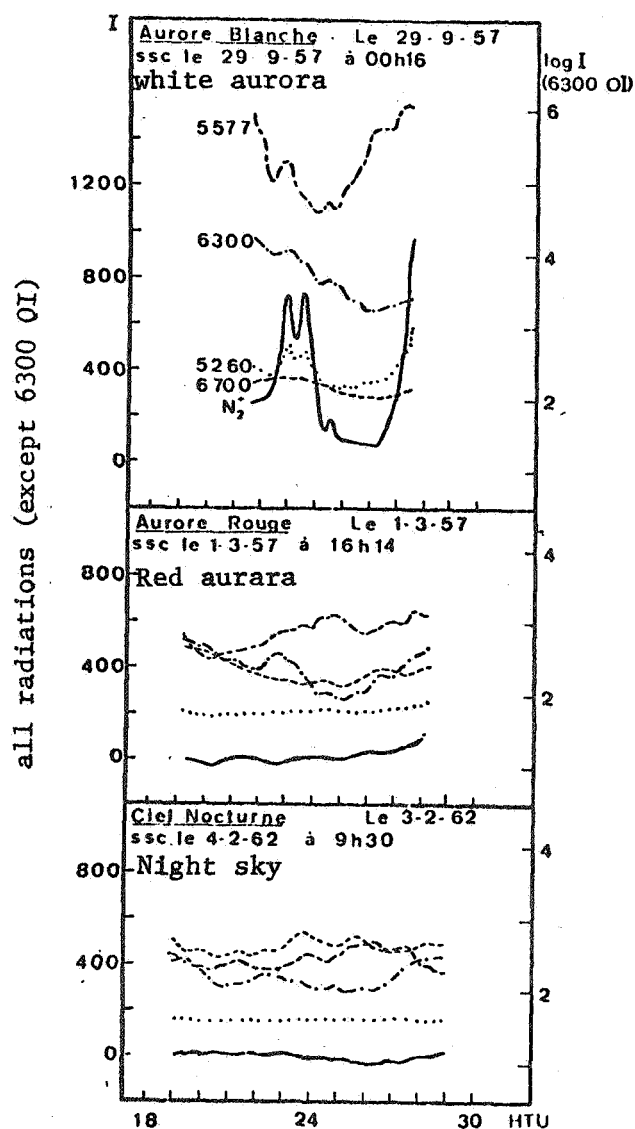


Fig.4. Three different types of night-time variations of principal radiations.

In normal period (night sky below) all the radiations vary slowly and in conformity with the known co-variation groups. In period of aurora or red arc (center) the duplet of oxygen at 6300 Å is selectively enhanced, sometimes by a considerable factor. The white aurora is characterized by the appearance of N_2^+ bands through 3670 and 4400 Å filters, which indicate then a co-variation shift with the intensity of the green line (above).

The intensity scales are linear (left) except for the red line, of which the very important variations practically impose a logarithmic scale (right hand side).

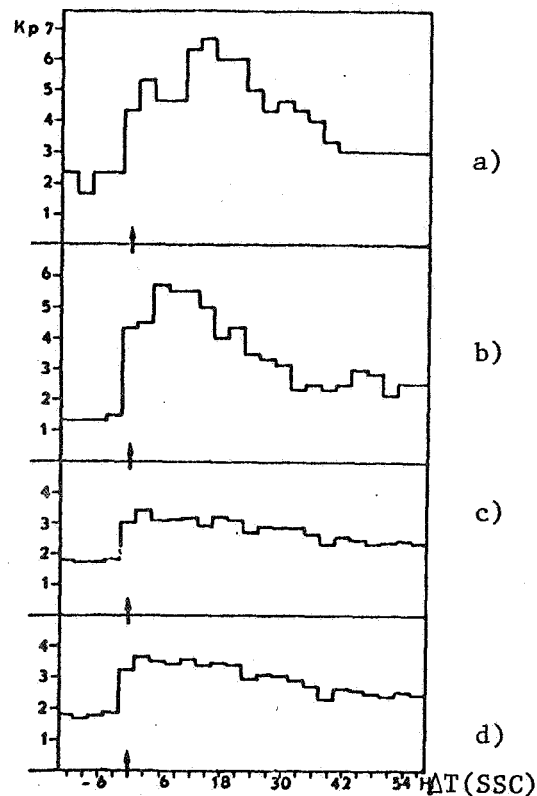


Fig.5

Mean Kp-index as a function of storm time, for different categories of storms classified at OHP according to their optical effects. The average Kp marked by vertical arrow is the one whose interval includes SSC. Horizontal strokes indicate the periods during which the aurora or the red arc was observed.

- a) 3 storms attended by a white aurora
- b) 6 storms attended by an arc or red aurora
- c) 44 storms without aurorae
- d) All storms

VARIATIONS IN THE AURORA PERIOD

a) White Aurorae

In the course of the 1953 through 1964 solar cycle, 15 white aurorae were observed at OHP in all. These aurorae are compiled in Table 5. All of them correspond to periods of very high magnetic activity (with a single exception noted in the table), and set in most often in the case of a SSC and at the beginning of the main phase. Of this aggregate only 3 are here analyzed. These aurorae, illustrated by Fig.6, are characterized by the appearance of N_2^+ bands, a very important enhancement of 6300 OI and an attenuation of group-B radiations (bands OH, Na). The green line is also affected but much less than the red line, the ratio $\Delta Q_{6300} / \Delta Q_{5577}$ being of the order of 300. The large filters centered on 4400 and 5260 follow the variations of the 3760 filter on account of N_2^+ band emission at 4278 and possibly of the forbidden duplet of NI at 5199 A respectively.

T A B L E 5

WHITE AURORAE

DATE	Hour of OBSERVATION	Hour MAXIMUM	Q MAXIMUM	CLASS	PÖLE	Kp MAXIMUM	Remarks
21/ 1/57	17.40-23.20	22.30	134000	A	17000	9—	Red arc. Aurora visible
28/ 1	20.30- 5.35	22.00	?	A		2+	Aurora visible. Exceptional aurora
30/ 6	20.40-23.40	22.30	9200	A	1600	8+	Aurora visible. Other maxim at 2100 & 2140 h.
2/ 9	23.30- 3.20	23.30	6600	Q	> 1400	8—	Aurora visible.
4/ 9	1.30- 3.20	2.00	6400	A	2100	8+	Red arc. Aurora visible.
21/ 9	20.50- 3.30	21.20	5400	A	370	7—	Aurora visible
22/ 9	2.10- 4.10	4.10	11800	A	2150	9—	Aurora visible. It is there since the beginning of the night, but
23/ 9	18.30- 3.40	18.30	7600	Q	> 2900	7—	overcast Aurora visible. Red arc. White aur.max. at ~2040 h.
29/ 9	21.20- 4.20	23.00	49000	A	6960	8 ₀	Red arc. Aurora visible.
26/11	21.00- 4.40	23.30	3380	A	250	6+	Ib.
8/ 7/58	21.30-23.00	21.40	> 12000	A	13000	9—	Cloudy. Red arc. Aurora visible.
4/12	18.20- 0.40	0.20	14700	A	1100	7 ₀	Cloudy. Red arc. Aurora visible. Several maxima.
17/12	0.20- 5.50	2.40	3900	A	350	7 ₀	Aurora visible.
29/ 6/60	22.10- 2.10	2.00	250	Q	100	7 ₀	
22/ 9/63	20.00- 4.05	21.25	1100	Q	300	9—	

The three white aurorae appeared in the course of the main phase of the storms, their intensities being maximum 9, 22 and 12 hours respectively after the corresponding SSC. There exists a marked correlation between the logarithmic intensity of 6300 OI and the ΔH Chambon (Fig.7). For $-\Delta H > 95\gamma$, this statistical correlation is written (see Fig.7 next page) :

$$\text{Log } I_{6300} = 0,017(-\Delta H) + 0,688,$$

or yet for $-Dst > 185\gamma$:

$$\text{Log } I_{6300} = 0,011(-Dst) + 0,246.$$

The small number of white aurorae observed does not allow us to draw a conclusion of their variation in local time. We shall only note that of 15 aurorae, 10 had an intensity maximum in the course of the first part of the night (Table 5).

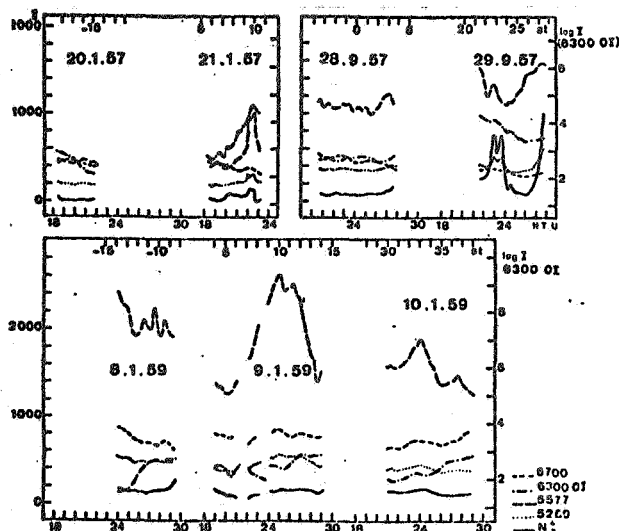


Fig.6

Variations in the course of three storms accompanied by a white aurora. The lower scale in abscissa is UT, the upper scale is the time counted in hours starting from SSC instant.

The compared examination of aurora and ionosphere variations makes it evident that in the course of intense aurora period, the measurement of the critical frequency $f_0 F_2$ is made imprecise by the presence of the sporadic F-layer. In this case the ionospheric values are plotted in a special fashion in Figure 8; the divergences between the intensity of the red line and of that which would be derived from the semi-empirical formula of the D. Barbier correlation (1963) are very important.

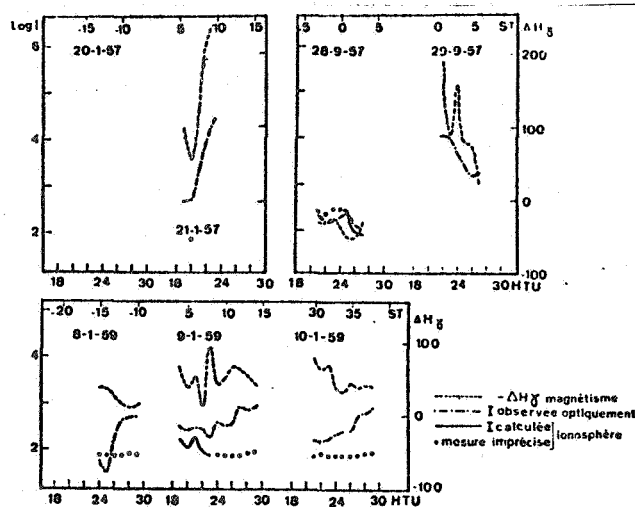


Fig.8

Variations in the course of storms accompanied by white aurora of magnetic amplitude ΔH , and of the red line intensity as observed, and, on the other hand, computed by the Barbier formula after ionospheric parameters.

Note the bad correlation between optical and ionospheric variations. The ionospheric measurements are often made imprecise by the presence of diffusive echoes.

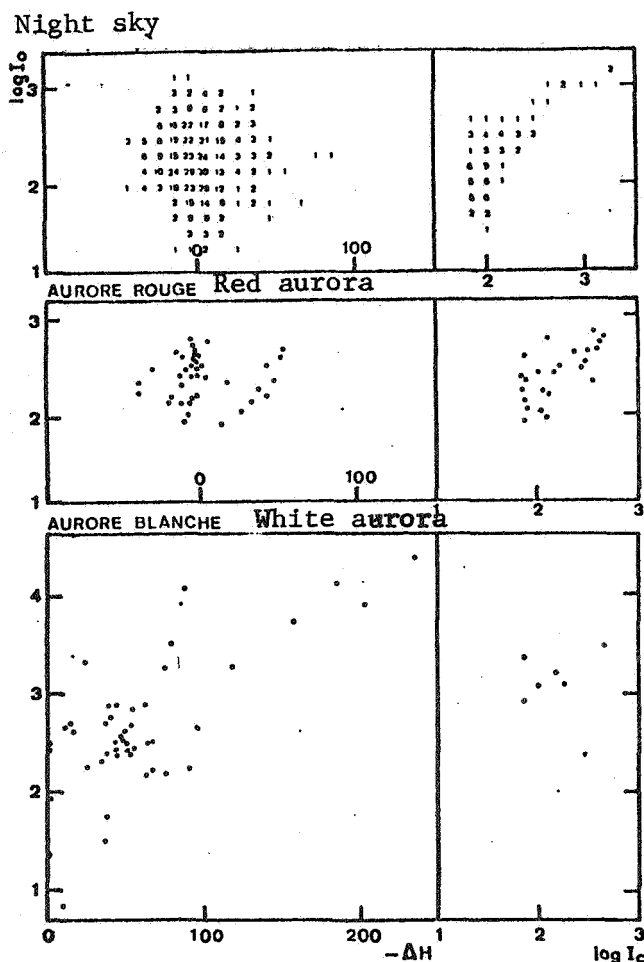


Fig.7

Correlation between the logarithmic intensity of the red line 6300 OI the amplitude of the magnetic variation (in abscissa to the left) and the parameters of the ionospheric F-region. (the logarithmic intensity being computed by the Barbier formula and plotted in abscissa to the right). Note the dissimilarity between the three categories of storms considered by this article (night sky, on top; red aurora in the middle, white aurora below). The two lower graphs have borrowed the data presented in Figures 8 and 11. The absence of correlation between the red line and the magnetic amplitude variation can be noted in a normal period of night sky, while at the same time the correlation is good between the red line and the recombination rate of the F-region. During white aurora period the situation is reversed.

b) Red Aurorae and Red Arcs.

During the whole of the solar cycle, 127 aurorae and 11 red arcs were observed at the Haute Provence Observatory (OHP) (Table 6, following pages).

T A B L E 6

RED AURORAE

Date	Hours of observation	Hour maximum	Q maximum	Class	Pole	K _p maximum	Remarks
10/ 3/56	20.00- 4.10	1.50	730	A	0	6 ₀	Another maximum at 23 0 h.
3/ 8	20.30- 2.10	22.30	190	Q	0	2—	
3/ 9	19.30- 2.30	1.40	150	Q	0	2+	
8/ 9	19.30- 1.00	20.40	440	Q	0	6 ₀	
26/10	17.50-23.10	20.40	2900	A	190	7—	Another maximum at 2310 h.
9/11	1.30- 3.40	2.40?	3600?	A	190	6 ₀	Very cloudy. Observed on
10/11						7—	Ph.II at about 0100 h.
27/11	20.50- 2.40	0.40	2400	A	0	5+	Starts suddenly at 2250 h.
2/ 1/57	19.50- 5.00	22.40	4300	A	80	5 ₀	
21/ 1	17.40-23.20	22.30	134000	A	17000	9—	Red arc. Aurora visible.
22/ 1	19.50-20.30	20.30	330	Q	0	3 ₀	
28/ 1	20.30- 5.35	22.00	?	A		2+	Exceptional aurora and visible.
29/ 1	18.00- 5.30	3.00	550	Q	0?	6—	
1/ 3	18.40- 4.10	4.10	400	A	60	8+	Sudden start at 2230 h.
2/ 3	18.40-20.50	?	> 900	Q	0	6+	Sky very cloudy
27/ 3	22.30- 3.40	1.10	2100	Q	380	7 ₀	
29/ 3	19.40- 1.30	19.40	1800	Q	410	6+	
19/ 4	19.50-23.10	19.50	650	Q	0	5—	
25/ 6	21.00- 1.30	1.30	860	Q	150	5 ₀	Another maximum at 2130 h
26/ 6	21.20- 2.00	21.20	1200	Q	170	5+	
2/ 7	22.20- 2.00	2.00	950	Q	?	6—	According to photo II, another maximum probable at 2300 h.
19/ 7	21.30-22.50	21.30	690	Q	0	4+	
3/ 8	23.20- 2.50	1.00?	220	Q	?	5+	Very cloudy
29/ 8	20.30- 1.00	0.50?	1200	Q	150	7—	Another maximum at 2140 h.
4/ 9	1.30- 3.20	2.00	6400	A	2100	8+	Red arc. Aurora visible.
23/ 9	18.30- 3.40	18.30	7600	Q	> 2900	7—	Ib. White aurora maximum at about 2020 h.
29/ 9	21.20- 4.20	23.00	49000	A	6960	8 ₀	Red arc. Aurora visible.
14/10	18.10-20.20	19.20	100	Q	0	4 ₀	
15/10	18.10-21.30	21.30	60	Q	0	3+	Doubtful aurora
20/10	19.40- 1.00	22.50	2300	A	0	4 ₀	Sudden comm. at about 2230 h. Secondary maximum at 0100 h.
21/10	17.50- 4.50	23.50	2000	A	50	7—	
22/10	19.50- 4.50	2.30	240	Q	0	5 ₀	
28/10	21.10- 4.50	2.00	460	Q	0	4—	
29/10	22.00- 4.50	23.10	880	A	50	4—	
25/11	21.50- 0.30	0.00	380	A	60	4+	Very cloudy
26/11	21.00- 4.40	23.30	3380	A	250	6+	Red arc. Aurora visible.
27/11	22.10- 5.30	23.00	270	Q	0	4 ₀	
19/12	17.20- 5.50	22.15	210	A	0	4—	
30/12	2.30- 5.50	2.35	2500	Q	2100	6+	

T A B L E 6 (continued)

RED AURORAE

Date	Hours of observation	Hour maximum	Q maximum	Class	Pole	Kp maximum	Remarks
17/ 1/58	20 30- 5.40	3.15	200	Q	0	4+	
11/ 2	18.30- 1.30	18.30	6400	Q	10400	6 ₀	Red arc.
12/ 2	18.20- 2.50	20.05	200	Q	120	6 ₀	Very cloudy An- other maximum end
13/ 3	22.40- 1.00	22.40	290	Q	60	2+	Very cloudy [of night]
18/ 3	19.00- 4.30	3.50	200	Q	180	4+	
21/ 3	19.00- 4.20	1.25	260	Q	100	6 ₀	
17/ 4	19.40- 3.30	22.40	500	A	150	6 ₀	
18/ 4	20.10- 3.30	23.10	290	Q	0	5+	
17/ 5	20.30- 2.30	?	?	?	0	4+	Very cloudy
7/ 6	21.10-23.00	21.10?	?	Q	0	4-	Ibid.
10/ 6	21.10- 0.20	?	?	?	0	5-	Ibid.
21/ 6	23.10- 1.50	?	?	?	170	6 ₀	Ibid.
8/ 7	21.30-23.00	21.40	> 12000	A	13000	9-	Red arc. Aurora vi- sible. Cloudy.
21/ 7	21.50-23.20	22.40?	660	Q?	220	6+	Very cloudy
17/ 8	20.40- 1.50	23.55	1600	A	190	7+	
5/ 9	19.20-21.20	19.20	1800	Q	0	6-	
7/ 9	20.10 23.10	22.00	660	A		4 ₀	Of few min.duration only
16/ 9	20.30- 2.00	0.50?	> 350	?	220	5+	Very cloudy
22/10	1 40- 4.20	?	> 850	Q?	70±	5+	Very cloudy
4/12	18.20- 0.40	0.20	14700	A	1100	7 ₀	Cloudy. Several maxima Red arc. Aurora vis.
14/12	20.20- 5.20	?	> 700	Q	50?	4 ₀	Cloudy
5/ 1/59	17.32-23.24	21.30?	> 2600	A	70?	6-	Very cloudy
9/ 1	17.30- 6.02	23.35	> 2600	A	200	6+	Cloudy at beginn.
10/ 1	17 32- 5 35	22.05	1200	A	60	5+	Arc formed at end of night. Abnormal prod. (weak aurora)
14/ 2	23.53- 5.30	5.30	520	Q	0	6-	
16/ 2	1.41- 5.30	3.30	620	Q	360	6-	Sharp arc form.
27/ 2					70	5 ₀	Photo III in trouble
28/ 2					70?	6-	Ibid.
1/ 3					70?	4+	Ibid.
8/ 4	19.22- 2.55	0.30??	?	?	0	6 ₀	Very cloudy
9/ 4	19.22- 0.05	?	?	?	0	5+	Very cloudy
11/ 4	21.25- 3.40	22.30	150	Q	0	5 ₀	
4/ 5	20.35- 2.20	2.20	600	Q	180	6+	
11/ 5	21.55- 2.45	2 45	700?	Q	50	7 ₀	
15/ 5	0.20- 2.40	2 40	700?	Q	0	6 ₀	
27/ 6	21.00-23.30	22.46?	1800?	Q	50?	5 ₀	
28/ 6	21.06-23.54	?	1300?	Q	50?	3+	Concealed by clouds
29/ 6	21.03- 0.18	?	> 1500?	Q	50?	6+	Very cloudy
30/ 6	20.53- 0.59	?	?	Q	50?	3 ₀	The aurorae of 27 - 30 June look like ano- malous twilights, but azimuths shifted tow.N.

T A B L E 6 (continued)

RED AURORAE

Date	Hours of observation	Hours maxima	Q maximum	Class	Pole	Kp maximum	Remarks
4/ 7	20.50- 2.14	?	?	Q	100?	4 ₀	Ibid.
11/ 7	22.20- 2.03	?	> 600	Q	350	6+	Ibid.
6/ 8	20.14- 3.01	23.46?	180?	Q	540	5 ₀	Very weak arc forms
3/ 9	19.59- 3.05	23.33	6800	A	1000	8—	
3/10	18.43- 4.00	22.01	370	A	100	7 ₀	
30/10	18.59- 4.30	?	?	?	0	6—	Very bad
1/11	17.40- 4.58	23.49?	160?	Q	50	6—	
2/11	17.46- 4.58	0.00?	160?	Q	0	6+	Forms very weak arc
2/12	18.40- 5.43	4.21	750	Q	340	5 ₀	
5/12	22.00- 5.30	22.00	1030	Q	100	6+	Weak arc.
31/ 3/60	22.35- 2.44	22.35?	> 4900	A	1500	9—	Very cloudy
1/ 4	23.01- 4.01	23.01	470	Q	300	7+	Also at strong max.S
2/ 4/60	23.53- 3.06	?	?	?	0	7+	Existence somewhat in doubt
23/ 4	19.42- 3.12	?	> 260	Q?	100?	7—	Very cloudy
24/ 4	19.54- 2.59	1.21	400	Q	50?	7—	
27/ 4	19.58- 3.31	23.34	940	Q	100?	7 ₀	
28/ 4?	20.48- 3.14	1.17	270	Q	0	6+	
30/ 4	22.36- 3.12	22.36	≥ 210	Q	450	7 ₀	
15/ 7	21.20-23.10	21.30	250	Q	50	8 ₀	Very cloudy
16/ 7	20.35-23.55	20.58	500	Q	100	5—	
16/ 8	19.55- 0.05	20.20	1200	Q	650	6+	Cloudy at end of night
17/ 8	19.50- 0.50	20.00	950	Q	0	6+	Clouds at beginn. and end. Exists at beginn.
19/ 8	20.05- 2.50	22.14	30	Q	0	5+	
29/ 8	22.30- 3.45	3.37	1700	Q	40	7 ₀	
13/11					670	8 ₀	No registration at 75°.
9/ 1/61	18.00-23.50	21.27	20	Q	0	5 ₀	
17/ 2	19.50- 5.15	2.07	50	Q	70	7—	
11/ 5	20.15- 2.45	21.22	450	Q	200	3—	Exists at beginning.
13/ 7	21.00- 2.20	21.13	980	Q	330	6+	Exists at beginning. Maximum at the S. Starts again from 0055 h. on.
14/ 7	23.00- 0.20	?	?		0		Very cloudy.
15/ 7	21.25- 2.25	?	?		0		Very cloudy at beginn.
17/ 7	21.30- 2.35	21.47	190	Q	0	6+	Exists at beginn.of night
2/ 8	20.25-22.30	20.33	200	Q	0	3+	Ibid.
1/12	18.00- 0.50	21.05	180	Q	0	5+	Cloudy at beginn.of night
30/ 4/63	1.25- 3.05	1.35	120	Q	0	6 ₀	
25/ 6	22.30- 2.10	1.12	450	Q	70	6—	
17/11	18.30-21.00	20.30		Q	400	4 ₀	Very cloudy. No registration at 75°.
9/ 5/64	20.20- 2.50	0.13	250	Q	70	3 ₀	Maximum to the S.
10/ 5	20.25- 2.40	20.44	600	Q	120	5—	Exists at beginn.of night
8/ 6	21.00- 2.10	21.24	500	Q	80	1+	Ibid.
9/ 6	21.05- 2.10	21.37	60	Q	0	1+	

T A B L E 6 (continued)

RED AURORAE

Date	Hours of observation	Hour maximum	Q maximum	Class Pole	Kp maximum	Remarks
10/ 6	21.30- 2.05	1.58	70	Q	0	5— Cloudy at beginn.night
13/ 3/66	19.15- 1.15	23.10	140	Q	20	6—
24/ 6/66	0.00- 2.00	2.00	500	Q >	100	5— Aurora accomp.by arc.
15/ 7/66	21.00- 1.30	22.50	200	Q	20	4+ SSC on 15th at 1500 h.
16/10/66	18.30- 4.30	0.30	100	Q	70	3— Ibid. at 0954 h. Kp attains 6 ₀ during the day of 16th.
7/ 1/67	18.00- 2.50	2.50	400	Q	40	6+ SSC at 0759 h.
13/ 1/67	19.15- 4.50	2.05	1400	Q	80	7+ SSC at 1202 h.
7/ 2/67	18.25- 5.25	22.00	4000	Q	120	6+ SSC at 1636 h.

T A B L E 7

	6300	6700	5577	5260	3670	Log 6300 [OI]	According to the ionosphere Log 6300 [OI]	6700, OH	5577	N ₂ ⁺	
21/1/57 { 22.00	7947	331	590	225	486	(873)	—	165	387	51	Aurores blanches White aurorae
20/1/57 {	120	379	412	172	362	300)	—	251	257	11	
Difference	7827	— 48	178	53	124	(573)	—	86	130	40	
29/9/57 { 23.00	11454	414	1311	504	1389	(923)	—	42	857	725	
28/9/57 {	189	389	997	252	593	(362)	(434)	402	769	— 32	Aurores rouges Red aurorae
Difference	11265	25	314	252	796	(561)	—	160	88	757	
1/3/57 { 23.00	315	349	558	196	406	(432)	(347)	204	381	— 25	
27/2/57 {	138	317	713	226	507	(319)	(328)	150	509	3	
Difference	177	28	— 155	— 30	— 101	(113)	(19)	54	— 128	— 28	Aurores rouges Red aurorae
29/8/57 { 24.00	265	319	647	215	447	(408)	(279)	160	453	— 25	
28/8/57 {	136	456	924	281	587	(317)	(288)	248	671	5	
Difference	129	— 137	— 277	— 66	— 140	(91)	(— 9)	— 88	— 218	— 30	

Aurorae and red arcs were observed during 9 of the 53 storms analyzed here. All these events appeared to be connected with important magnetic disturbances, either in period of SSC magnetic storms (77 cases) or in period of disturbances with gradual commencement (50 cases). For the 9 storms and during the period from 6 to 36 hours after the SSC, ΔH Chambon is -32γ .

The only certain effect is that of the red line which is considerably enhanced. It seems also that the green line increases gradually starting from the second day after the commencement of the storm.

The variations of these two radiations are illustrated in Figures 9 and 10. The small number of observations precludes the revelation of variations for other radiations, which are not represented.

The diurnal variation of the red line is "two-mode". There exists a relatively important minimum at about 2330 h UT, the maxima taking place at more or less 2200 (main maximum) and 0200 h (secondary maximum). This variation is to be compared with the frequency of appearance of the aurora at the same station, (D. Barbier, 1958). The green line variation, provided it is real, is reversed. It seems that we have to do with the enhancement of the diurnal variation of this emission.

The intensity maximum of the red line is attained at about 36 hours after storm commencement, that is, during the recovery stage. The correlation of the intensity logarithm of the red line and of the digression of the horizontal component ΔH does not differ from what has been observed for the white aurorae. (Refer to Fig.7).

The correlation of observed and calculated intensities is not good, according to Barbier's calculations (Fig.11).

Table 7 on the preceding page points to the importance of effects on each radiation in the course of white aurorae and particular red aurorae.

2. EFFECTS OF MAGNETIC STORMS ON

THE NIGHT SKY

a) Method of Analysis

The statistical treatment of measurements obtained during the storm period is performed in several stages: the analogic registration is at first digitated and plotted on charts punched with the aid of a curve reader.

Conversions are then performed and the variations are drawn for each of the radiations as a function of time. This first treatment allows an individual consideration of storms; moreover, on this occasion the erroneous measurements, of which the percentage is very low, may be detected. The corrected measurements are then treated by the method of superimposed epochs (Chapman & Bartels, 1940). The variations as a function of storm development are determined

AURORAE AND RED ARCS VARIATIONS IN TIME OF STORMS

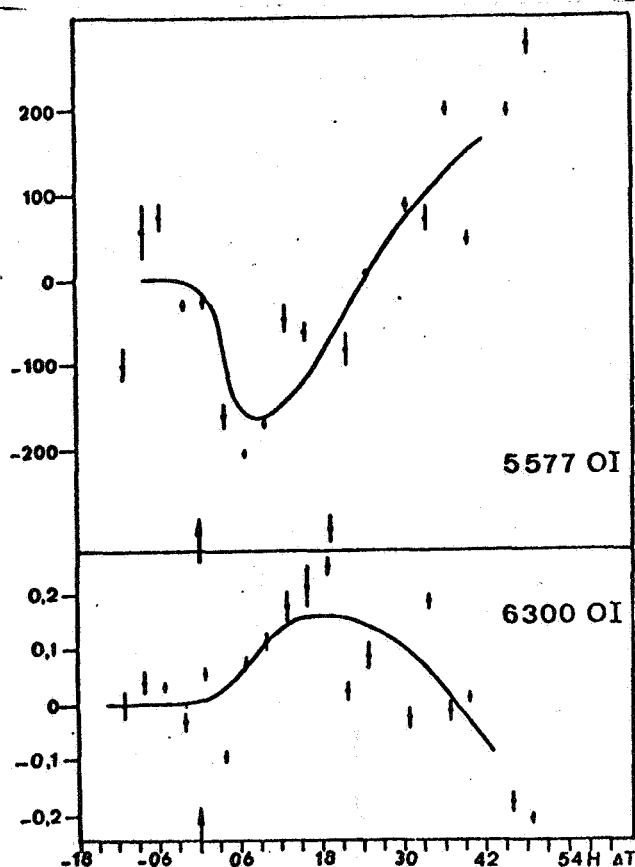


Fig.9. Aurorae or red arcs' variations as a function of storm time. Variation of the average intensity of oxygen's red and gree lines as a function ot time counted in hours from the SSC. In each 3-hour interval (the first going from -12 to -9 hours) the mean values of all the observations and the probable error of this average, are computed in the optimistic hypothesis that these measurements are independent anf of Gaussian distribution. The values were preliminarily corrected for the diurnal variation by subtracting the mean monthly value at the closest round half-hour. For the red line the calculations and the Figure are expressed in logarithmic intensities, The scale of the corresponding ordinates is calibrated in logarithms of base 10. The same convention apply to the subsequent figures

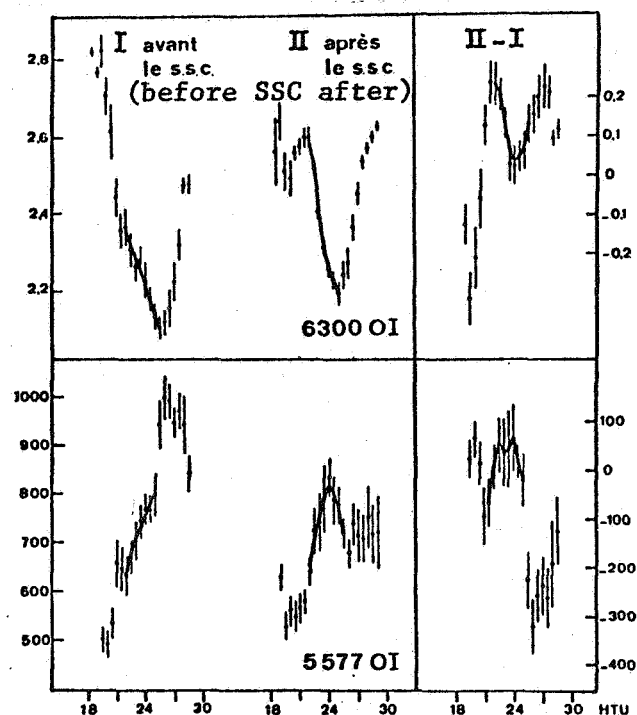


Fig.10. Aurorae or Red Arcs. Diurnal variations. This fig. represents the diurnal variation of the mean intensities of oxygen lines in the course of the 24 hours that precede the storm, during the storm and their differences. Only the periods observable year round were joined by solid lines. Outside these periods the results are doubtless affected by the annual variation of intensities. To be noted is the relative minimum of the red aurora toward midnight and also the inverse effect, more questionable, for the green line.

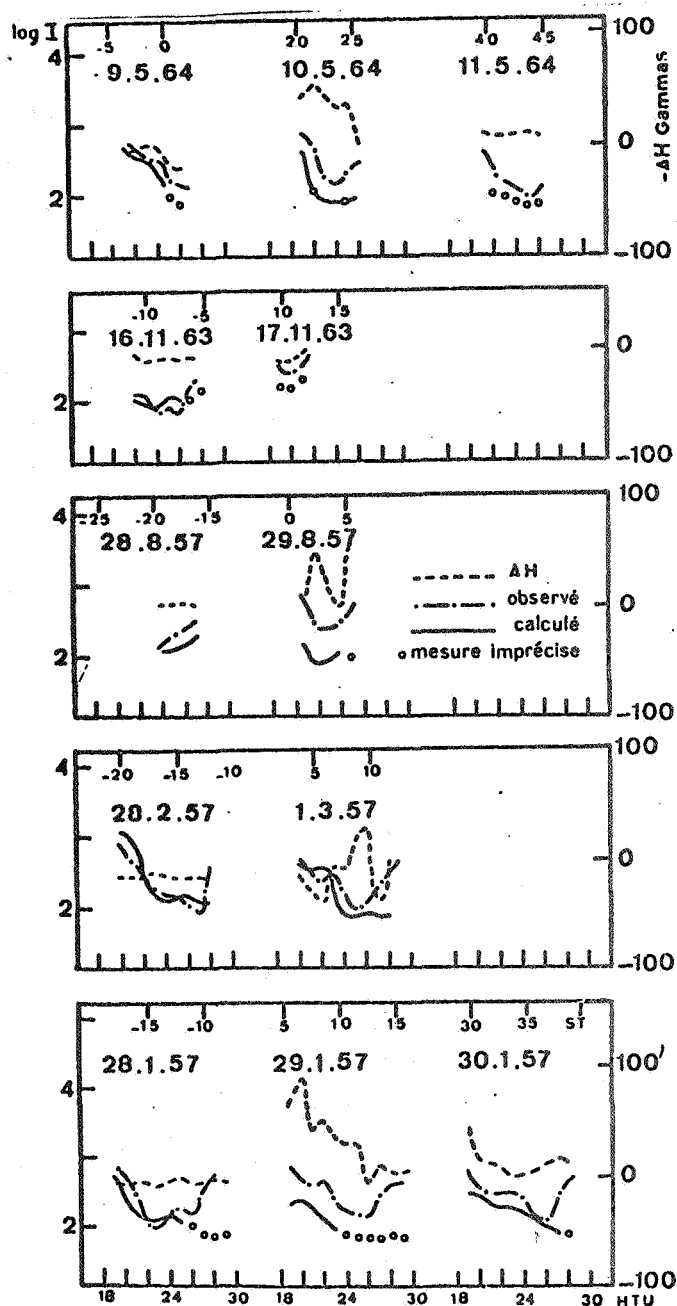


Fig.11. Variation of the red line, of the ionosphere and of the terrestrial magnetism during the aurora and red arc periods; the conventions are the same as for Fig.8. Note that the intensity of the line 6300 OI during the aurora is distinctly more important than what is indicated by the Barbier's formula.

by distributing the measurements within 23 intervals of 3 hours, from 12 hours prior to 57 hours after the instant of the SSC. The diurnal variations are determined by distributing the observations obtained during the 12 hours preceding the SSC on the one part, and between 6 hours prior and 36 hours after the SSC on the other; they are analyzed as a function of UT by 30-minute intervals. In each interval the program computes the mean values and the standard errors on the average values:

$$E = ((\sum y_i^2 - \sum^2 y/N)/N(N-1))^{1/2}.$$

This formula could be validly applied to independent measurements of Gaussian distribution.

In fact it is here very optimistic, for the immediately consecutive measurements, counted within one and the same interval, are strongly correlated. The standard errors indicated in the tables and plotted in the figures by uncertainty strokes are thus likely underestimated by a factor of 3 and 2 for the variations with the time of the storm and the diurnal variations respectively.

One is aware that the night sky light is subject to seasonal and diurnal variations of great amplitude. Although the studied storms are distributed in a fairly homogenous manner (see Figs.1 and 3), it is necessary to correct the results of these systematic variations. The above-described calculations were thus taken up again after subtracting from each intensity the average one obtained during the same lunation at the nearest exact half-hour. This procedure improves considerably the precision of storm effect determination. Only an abstract of the effects that seem most significant to us will be presented in the following.

b) Results at the Haute-Provence Observatory (OHP)

The 44 storms retained for analysis of variation of night sky light according to the above criteria are all characterized by a main phase of feeble amplitude (Fig.5). The ΔH Chambon extreme is of -82γ , whereas the mean ΔH Chambon during the storm (from 6 to 36 hours after SSC) is relative to the value prior to SSC of only $-16 \pm 16\gamma$. The mean value of each of these radiations during 12 hours preceding the SSC on the one hand, and during the main phase (6 to 36 hours after the SC), on the other, is presented in Table 8. It appears that in the course of the main phase the following radiations are enhanced:

$$\begin{aligned} 6300 \text{ OI} &\simeq +4 \pm 2 \% \\ 5577 \text{ OI} &\simeq +5 \pm 2 \% \\ 3670 &\simeq +2 \pm 1 \% \\ \text{continuum} &\simeq +2 \pm 1 \%. \end{aligned}$$

On the contrary, the following radiations are attenuated:

$$\begin{aligned} 6700 \text{ OH} &\simeq -8 \pm 2 \% \\ 6300 \text{ OH} &\simeq -7 \pm 1 \% \\ 5893 \text{ Na} &\simeq -2 \pm 2 \% \end{aligned}$$

The calculation of probable errors shows that all the effects, with the exception of the effect on sodium, are practically certain. One may notice that the correlations established by D. Barbier, between all the different radiations are found again in the effect of the storm and that each of the covariance groups behaves in a specific fashion.

The effect observed on the green line is independent of that announced by Christophe-Glaume (1963) and confirmed by Silverman and Bellew (1966). This last effect takes place during the 2 or 3 hours following the sudden commencement and is not taken into account in the above statistics.

Variations of the group A (5577 OI, Continuum, Herzberg).

- Dst-variation: a first enhancement of 6% appears soon after the sc, passes through a maximum toward $t + 1$ h and is then followed by a relative minimum at $+4$ h and by a slightly more important increase, but more spread, which attains its maximum at $+19$ hours. The decrease is then gradual till $+37$ h. It seems that there is then another, second outbreak, while the magnetic storm is practically ended (Fig.12).

- DS-variation: the enhancement due to the storm is clearer during the first part of the night (Fig.13).

The variations are of same type for all radiations of group A.

Variations of the Group B (OH, Na).

The dispersion of intensities of this group is important and, despite the amplitude of 8% of the storms, we dispose of too little information to enable us to make its form more precise. The variations of OH at 6300 and 6700 A are entirely parallel, whereas the variations of sodium duplet at 5893 A, are sensibly weaker than might be anticipated from the usual correlations, though they are of same direction.

T A B L E 8

VARIATION OF PRINCIPAL GROSS AND DECONTAMINATED (*) RADIATIONS DURING STORM PERIOD

9 storms accompanied by aurora or red arc (white aurora perioss excluded)		44 storms not attended by sensible auroral manifestations	
Averages before SSC	Averages* after SSC	Averages* before SSC	Averages* after SSC
Differences before SSC	Differences after SSC	Differences before SSC	Differences after SSC
257 ± 4	61 ± 6	220 ± 4	14 ± 1
393 ± 8	17 ± 5	386 ± 3	24 ± 1
551 ± 12	41 ± 5	436 ± 4	10 ± 2
325 ± 3	53 ± 9	820 ± 8	41 ± 4
212 ± 3	5 ± 2	225 ± 1	3 ± 0
206 ± 4	16 ± 1	213 ± 1	7 ± 1
226 ± 4	18 ± 3	528 ± 3	25 ± 1
378 ± 4	16 ± 3	219 ± 3	4 ± 2
198 ± 8	1 ± 2	348 ± 2	9 ± 1
273 ± 10	8 ± 3	171 ± 3	12 ± 1
197 ± 3	16 ± 3	260 ± 4	3 ± 2
111 ± 1	30 ± 5	617 ± 7	68 ± 4
101 ± 28	3 ± 2	198 ± 1	3 ± 1
	0 ± 2	12 ± 1	11 ± 1
	345	1852	3485
	421	1831	4 ± 16
	224 ± 43	12 ± 12	16 ± 16
	325 ± 51		

- Dst-variation: The variation is practically contrary to the corresponding variation of the group A. A similar effect to that affecting the green line, but with opposite sign (amplitude -7%) is observable within 2 hours following SSC.

- DS-variation: The effect is maximum during the second part of the night, feeble or zero at the beginning of it.

Variations of the Group C
(6300 OI)

- Dst-variation

The red line passes by a first maximum during the 12 hours that follow SSC; it then returns to its normal value, then increases again; a 2nd maximum in amplitude, comparable to the first, takes place 24 hours later; this maximum is of the order of 5%.

- DS-variation: The effect of the storm increases in the course of the night and seems to pass by a maximum around 0200 hours LT. This variation is clearly different from the variation in the aurora or red arc period, which involves a marked minimum in the middle of the night.

Correlation of red line intensity with the magnetism and the ionosphere :

Storms of this category are weak, just as are the optical effects associated with them. Under these conditions the correlation of the magnetic digression - ΔH Chambon

NIGHT SKY : VARIATION IN TIME OF STORM

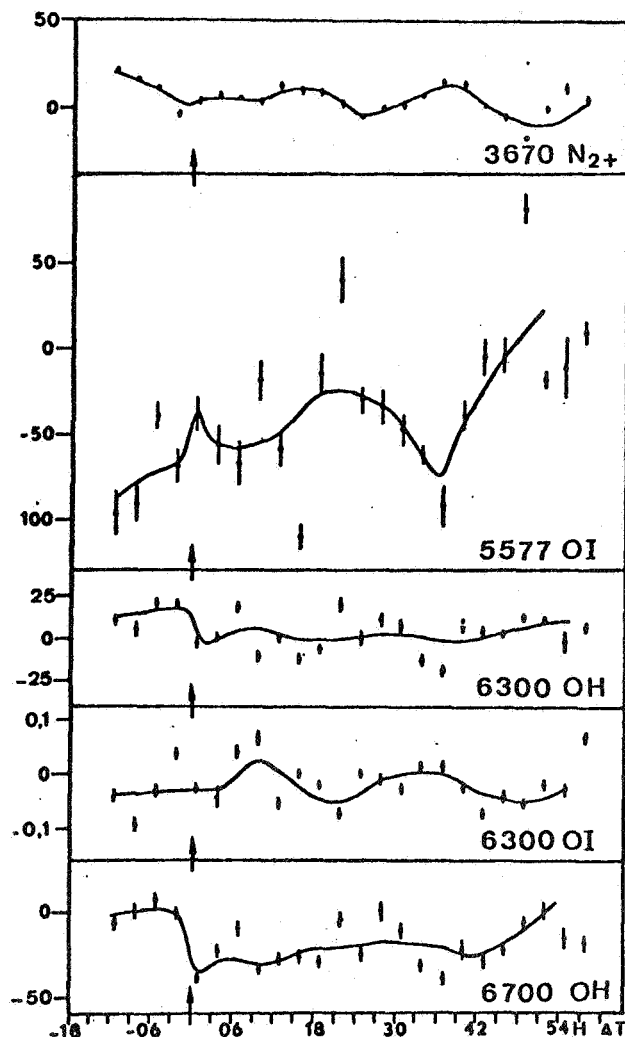


Fig.12. The conventions are the same as for Fig.9. Analysis refers here to 44 storms. We shall note:

- a) the absence of band N_2^+ enhancement (the weak variations being probably due to the imperfection of the correction formula);
- b) a positive effect on the green line 5577 A during the initial phase of the main storm phase, and the post-disturbance that begins 36 hours after the commencement of the storm;
- c) a weak effect, slightly doubtful, on the red line which shows a large maximum about 32 hours after commencement.
- d) a negative effect on the intensity of the OH bands (6700 and 6300 A) which varies in opposition with the green line.

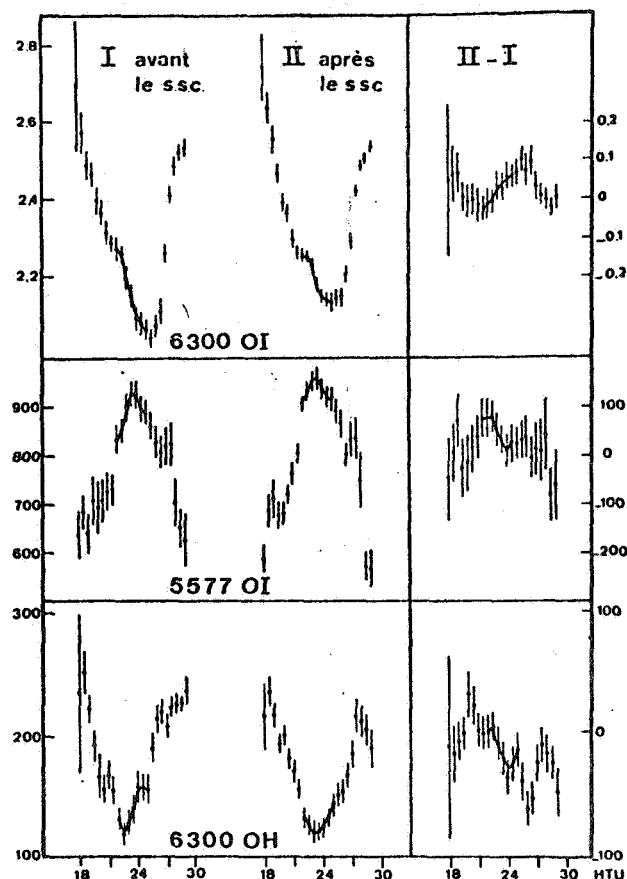


Fig.13. This figure, drawn according to the same conventions as in Fig.10, shows the absence of a sensible diurnal variation of the storm effect on the intensity of the oxygen lines and of the OH bands

and of the intensity of the red line is totally undetectable (Fig.7). The intensity of the red line remains strongly related to ionospheric parameters by the Barbier formula, less, however, than it is in a magnetoquiet period and at the beginning of the night. The intensity observed is frequently greater than might be expected from the altitude and the electron density of the F-region.

c) Results at the Tamanrasset Observatory (TAM)

The mean characteristics of storms analyzed at Tamanrasset are recalled in Figure 3.

Table 9 shows that in the course of the main phase the following radiations are enhanced:

4400	$\approx$	$3 \pm 1 \%$
5577 BA	$\approx$	$2 \pm 1,5 \%$
3670	$\approx$	$2 \pm 1,5 \%$

and, on the contrary, the following ones are attenuated:

6300 OI	$\approx$	$-18 \pm 4 \%$
6700	$\approx$	$-2 \pm 1 \%$
5893	$\approx$	$-4 \pm 2 \%$
6300 OH	$\approx$	$-3 \pm 1 \%$

With the exception of the red line, whose variation is rather important and of opposite sign to that observed at OHP, the effects are quite analogous at both stations. They differ, however, in some details.

Variations of the Group A.

Barbier and Glaume (1960b) have shown that at low latitudes, two regions of different altitude would contribute to the green line emission. The separation of these two components is made possible by the fact that the high emission of the green line remains proportional to the emission of the red line. This correction was applied in order to obtain the intensities of the green line at low altitude (5577 BA); it is particularly important in this case since the storm effect upon the two emission layers are of opposite sign.

5577BA shows a maximum about 18 hours after the commencement of the storm. Starting from the second day the observations are too scarce and dispersed to allow us to ascertain the second maximum that exists at OHP.

It is in the middle of the night that the storm enhancement is maximum; this is clearly shown in Fig.14 and in the example of Fig.15.

Variations of the Group B.

As far as can be judged from Fig.14, the variation in time of storm are of somewhat lower amplitude, but quite similar to those observed at OHP.

The intensity decrease characteristic of beginnings of normal nights does not exist in a storm period (Fig.16) and this is contrary to what is the case at the OHP; the storm effect is most important during the first part of the night.

TABLE 9

VARIATION OF PRINCIPAL GROSS AND DECONTAMINATED
RADIATIONS IN PERIOD OF STORMS AT TAMANRASSET

STORMS				
	Averages before SSC	Averages** before SSC	Averages** after SSC	Mean ** Differences
6300 OI *	838 $\pm$ 15	124 $\pm$ 8	-30 $\pm$ 6	-154 $\pm$ 10
6700	355 $\pm$ 3	7 $\pm$ 1	0 $\pm$ 1	-7 $\pm$ 1
5893	579 $\pm$ 8	29 $\pm$ 4	5 $\pm$ 2	-24 $\pm$ 4
5577	816 $\pm$ 8	25 $\pm$ 4	12 $\pm$ 3	-13 $\pm$ 5
5260	279 $\pm$ 3	- 4 $\pm$ 1	- 5 $\pm$ 1	- 1 $\pm$ 1
4400	263 $\pm$ 2	- 1 $\pm$ 1	6 $\pm$ 1	7 $\pm$ 1
3670	657 $\pm$ 6	3 $\pm$ 3	18 $\pm$ 2	15 $\pm$ 4
6700 OH *	226 $\pm$ 2	9 $\pm$ 1	2 $\pm$ 1	- 7 $\pm$ 1
log 6300 OI *	536 $\pm$ 4	8 $\pm$ 2	-11 $\pm$ 1	-19 $\pm$ 2
6300 OII *	419 $\pm$ 3	21 $\pm$ 1	7 $\pm$ 1	-14 $\pm$ 1
5577 OI *	428 $\pm$ 6	30 $\pm$ 3	19 $\pm$ 2	-11 $\pm$ 4
5577 BA *	677 $\pm$ 8	5 $\pm$ 4	19 $\pm$ 4	14 $\pm$ 6
Nbre d'obs.	802	802	1772	

N.B. ** denotes the decontaminated radiations at TAM

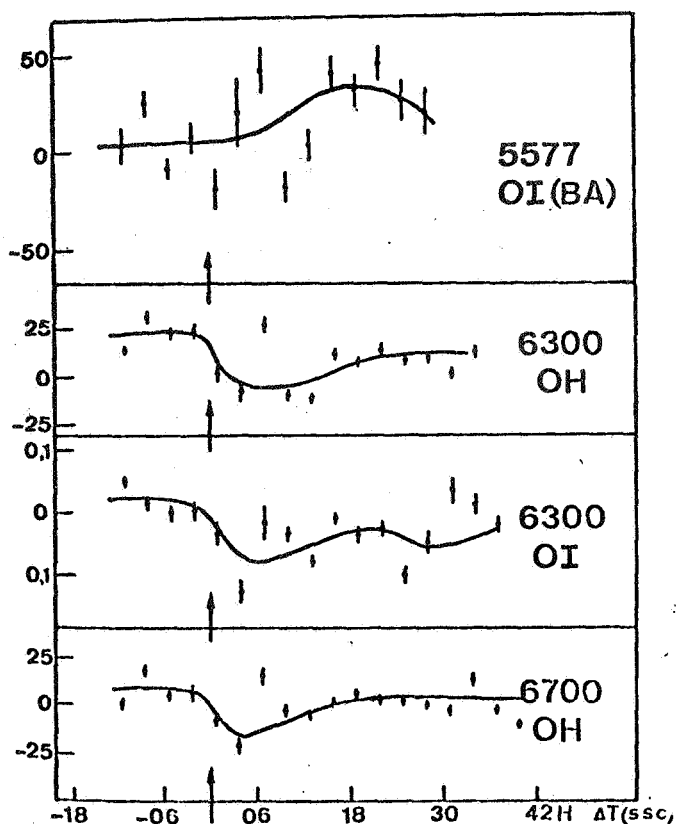


Fig.14. Variation of the night sky as a function of storm time at TAM. The conventions are the same as for Figures 9 and 12. The analysis refers to 44 storms. Note the similitude between the variations observed at TAM and OHP (Fig.12). Only the 6300 OI variations are of opposite direction at both these stations.

Variations of the Group C.

The variation of the red line 6300 OI is the most spectacular; contrary to what has been described for the Haute-Provence Observatory (OHP), its intensity decreases by about 25% in the course of the first 12 hours of the storm and offers a second comparable minimum about 30 hours after the SSC. In magnetoquiet period enhancements in the intensity of the red line are observed at Tamanrasset; they set in most often during the first part of the night and are due to the intertropical arc or emission spots into which the arc degenerates during the summer. In the course of the main phase of major magnetic storms these enhancements do not appear or are at least very attenuated. The disappearance of the intertropical arc in the course of a particular storm on 12 November 1960 was mentioned by Barbier (1962).

This would be interpreted as a systematic effect. The correlation between the red line intensity and the Dst-parameter (Sugiura) is narrow, as it is well illustrated in Fig.17.

The registrations are too scarce and the ionospheric and optical stations are too remote to enable one to discern a difference in the correlation of their registrations in magnetoquiet as well as in disturbed periods (Fig.17,b,c).

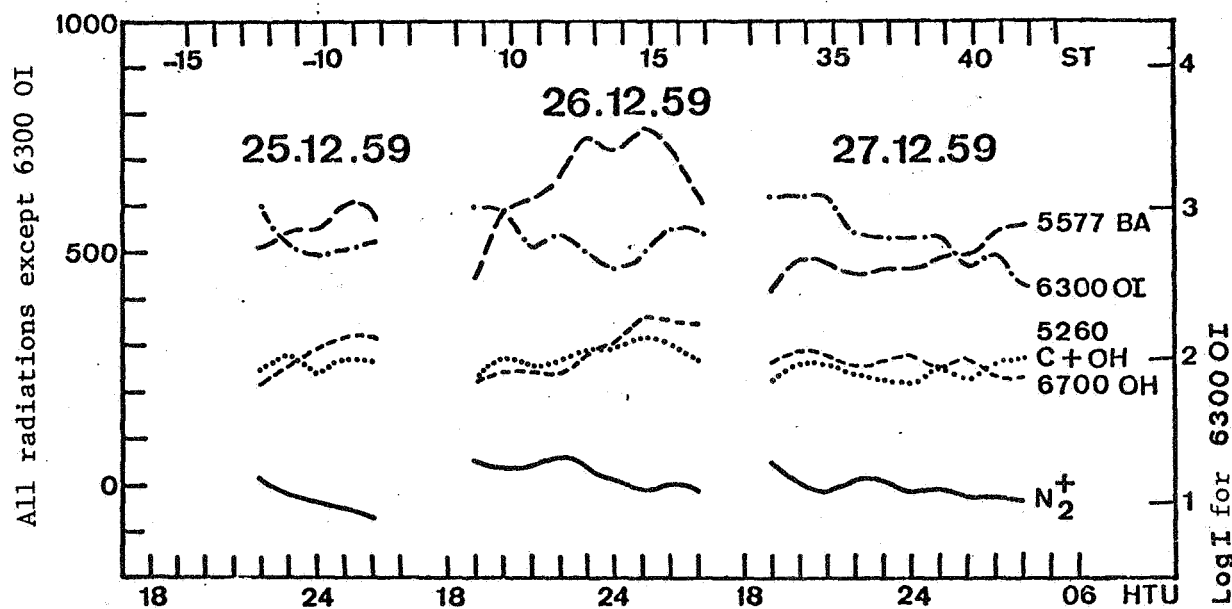


Fig.15. Example of variations observed in the course of an individual storm. One may notice for the night of 26 December 1959 an enhancement of the low altitude component of the green line and a relative attenuation of the red line at the beginning of the night

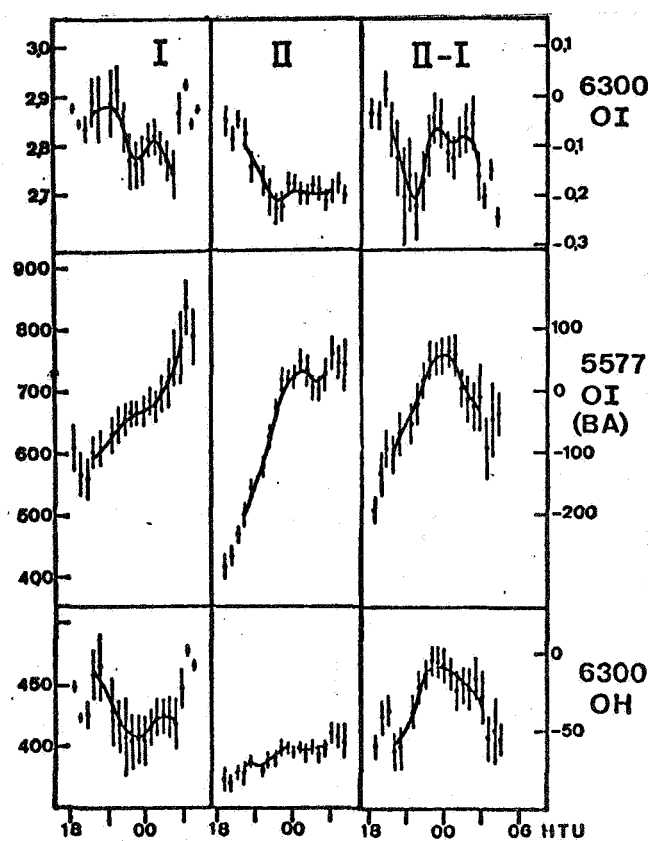


Fig.16. DS-variations of the night sky at TAM. The conventions in this figure are the same as for Fig.13, to which it must be compared

DISCUSSION

The present study has shown that the night sky emission at middle and low latitudes is little affected in the course of magnetic storms. The perturbations' amplitudes are summarized in Table 10. We shall discuss them by groups of increasing altitudes.

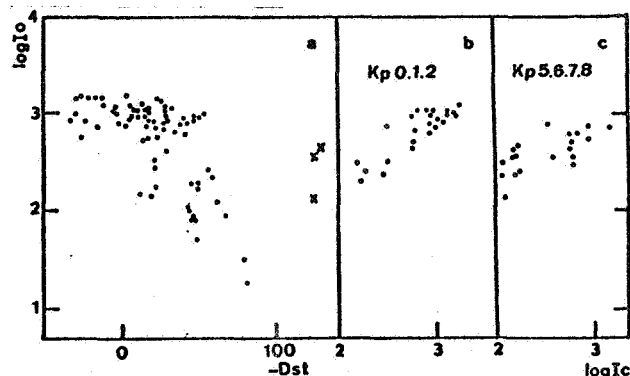


Fig.17. Correlation at Tamanrasset of the logarithmic intensity of the red line and the planetary magnetism and with the local ionosphere.

a) One may notice the strongly negative correlation with the energy of the storm characterized by the Δ st-index (Sugiura). The three points which depart from this correlation correspond to the eve of 17 Aug.1958. They may possibly indicate the presence of a low latitude aurora. Only the intensities observed in the direction of the celestial pole between 2100 and 2300 h.UT inclusive are represented. The intensity maximum of the arc is probably in anticorrelation still more narrow with Dst.

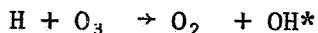
b), c) Correlation of red line intensity with that calculated by the Barbier formula, starting from the ionosphere, in magnetoquiet (b) and disturbed (c) period. The remoteness of the geographic zones makes the comparison imprecise.

TABLE 10

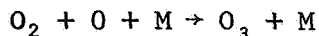
	OHP	TAM
Number of analyzed storms	53	18
Kp prior to SSC	1.76	2.35
Kp from 6 to 36 hrs after SSC	3.26	3.62
Variation of Group A 5577 OI	+5 percent	+2%
Variation of Group B OH, Na	-7 percent	-3%
Variation of Group C 6300 OI	4 percent	-18%

Group B (line D of sodium, OH bands).

One is aware that emissions of this group are excited at the mesopause level, toward 85 km altitude, by multiple chemical reactions between different allotropic forms of oxygen, hydrogen and their compounds. The most plausible excitation reactions currently are :



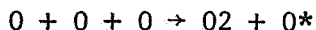
Ozone being formed by reactions of the type:



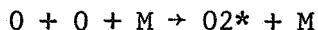
One is thus tempted to interpret the behavior of group B emissions by impoverishment in atomic oxygen at mesopause level in the course of magnetic disturbances.

Group A

The emissions of this group originate at the base of the thermosphere, toward 100 km altitude, and result in triple collision process:



(Chapman, 1931; Young O_2 and Black, 1966), which yields account of oxygen's green line excitation.



which accounts for the Herzberg's band excitation.

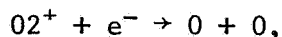
The enhancement of the green line during magnetic disturbances was already mentioned by Roach, Mac Caulley and Matsushita (1960) after Fritz Peak's observations. This excitement, as well as that of Herzberg's bands, might possibly be interpreted by reaction rate accretion with temperature, or, still more likely, by a relative increase of atomic oxygen maximum increase at the base of the thermosphere.

It is well known (Barat, 1966) that the transition region between the mesopause and the thermosphere is characterized by important turbulent exchanges. The results expounded here indicate that the mixing of this region of the atmosphere would be attenuated in periods of important magnetic disturbances. The explanation of such an effect could be sought for in the existence during these periods, of strong vertical temperature gradients.

Group C

This group includes red lines of oxygen and the green duplet of nitrogen at 5200. The excitation potential of red lines is of 1.97 ev. The

lifetime of $O(^1D)$ being of 110 seconds, the deexcitation by impacts is important below 200 km; the major part of the nighttime glow is emitted above that altitude. The prevailing excitation process is that of radiative electronic dissociation of O_2^+ :



in which both resulting oxygen atoms may be in the state (^1D). In the aurora the state (^1D) is mostly populated by inelastic electronic collisions, and this last process might play a role in the selective excitation of the red line of the nighttime glow, provided there exists a sufficient flux of electrons between about 2 and 7 ev.

The semi-empirical Barbier formula allows us to compute the contribution of the radiative dissociation to the total radiance of the red line by starting from ionospheric parameters h'_F and f_oF_2'' . In accord with the above it has been established that at low latitudes (Tamanrasset, Haleakala) the correlation of the computed radiances after the ionosphere with the observed ones is excellent (Barbier, 1962b, c). To the contrary, in the trans-auroral regions the correlation is practically undetectable [Weill, 1966]. At middle latitudes the correlation is rather good in the first part of the night and much more questionable toward morning hours [Barbier, 1963].

Elsewhere, the statistical study of ionospheric registrations has shown that the F-region is affected by important disturbances during magnetic storms [Martyn, 1953]. At the magnetic equator [Matsushita, 1959], an accretion of the total electronic content and of the electron density maximum is observed during the main phase. At tropical and middle latitudes a decrease in the total electron content of the ionosphere relative to mean level is observed to the contrary. These results have been confirmed by topside soundings of AES Alouette and by measurement of the Faraday effect [Potts, 1965; Arendt, Papayonou, 1965]. At middle latitudes this effect shows an important seasonal variation. On the other hand, the study of atmospheric braking of AES has shown (Lockwood & Nelms, 1964) the importance of upper atmosphere heating during perturbations. The temperature offers, relative to the magnetic activity, a lag of several hours [Jacchia *et al*, 1967]. Cole (1965) proposed to interpret the steady auroral arcs by heating of the F-region due to the redistribution of hot magnetospheric plasma during the main phase of magnetic storms.

At low latitudes (TAM), we have seen that during the main phase of a storm the intertropical arc tended to decrease in intensity, if not to disappear altogether. Barbier (1964) has indicated that the radiance of red intertropical arcs could not be explained by the recombination of only the local ionization, but ought to have resorted to transports of ionization possibly from the equatorial regions. A theoretical model of Hanson and Moffet (1966) has made this mechanism more precise. The increase in total electron content at the equator, just as the disappearance of the intertropical arc imparts the idea that the ionisation transports into the ionosphere region are less effective in magnetically disturbed periods.

At middle latitudes (OHP) we have shown that the radiance of oxygen's red lines rose slightly during the storm. The rate of excitation by radiative dissociation in a unit of volume is written:

$$k \cdot n(e) \cdot n(O_2);$$

the concentration of atomic oxygen is likely very stable and the enhancement of the red line could not be explained by an accretion of the term $n(e)$, since the total electron content decreases slightly during storms, without the altitude of ionization maximum being notably affected.

The coefficient k is a function still little known of temperature; the atmospheric heating in the course of an average storm classified "night sky" is of the order of $50^\circ K$ [Jacchia *et al*, 1967] and an increase by 3% of the excitation rate by this simple effect would not be unlikely. However, in this case the amplification of the storm would be mostly observed at the beginning of the night, while the opposite is noted. The effect variation in local time seems to indicate that the emission component linked with the dissociative recombination decreases during the main phase of the storm, and that this decrease is more than compensated by another emission mechanism. It is at any rate likely that the threshold adopted, after examination of the registrations, to classify the nights with red aurorae or "night sky", is not absolute. Nearly all magnetic storms would give rise during their main phase and their recovery phase to a stable auroral arc at middle latitudes, of which the radiance, which is a function of a rapidly growing importance of the storm, would most often be of only a few Rayleighs.

C O N C L U S I O N

The long series of measurements obtained at the Observatories of Haute-Provence and Tamanrasset allow us to conclude about the existence of characteristic light variations in the night sky in periods of magnetic storms. The attenuation of the line D of sodium and the OH bands constitute a new fact, concomitant with the enhancement of oxygen's green line, of Herzberg's bands and of the continuum. These effects point to the fact that the vertical distribution of atmospheric constituents and namely that of atomic oxygen, is slightly perturbed by the storm at the mesopause and the lower thermopause levels.

Analysis of high altitude emissions was conducted with precautions, for all the important perturbations are accompanied by auroral effects or para-auroral ones, observable at middle latitudes and exceptionally to tropics.

At the OHP the continual electron decrease of F-layer content and the temperature increase result in opposite optical effects which are partially compensated.

The ionization transport mechanism which is at the origin of intertropical arcs seems particularly sensitive to magnetic activity. The intertropical arc

North, toward Tamanrasset, attenuates or vanishes entirely during the main phase of storms.

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Appendix and Bibliography follow..

A P P E N D I X

LIST OF STORMS' SUDDEN COMMENCEMENTS ANALYZED IN THIS ARTICLE

a) Haute-Provence Observatory

27/10/54 à 07 h 47	9/ 1/59 à 14 h 59	28/ 9/62 à 12 h 56
11/ 2/56 à 0 h 53	12/ 1/59 à 11 h 24	21/11/62 à 13 h 54
8/ 7/56 à 01 h 02	5/12/59 à 06 h 59	26/12/62 à 08 h 09
2/10/56 à 05 h 45	29/ 1/60 à 02 h 05	18/ 6/63 à 02 h 58
5/10/56 à 07 h 05	23/ 5/60 à 11 h 36	15/ 7/63 à 21 h 14
21/ 1/57 à 12 h 55	21/ 6/60 à 0 h 13	17/11/63 à 09 h 03
24/ 1/57 à 19 h 10	19/ 8/60 à 16 h 16	16/ 1/64 à 01 h 35
29/ 1/57 à 13 h 13	13/ 4/61 à 14 h 50	12/ 2/64 à 06 h 04
1/ 3/57 à 16 h 14	14/ 6/61 à 23 h 35	8/ 4/64 à 08 h 08
27/ 7/57 à 19 h 59	13/ 9/61 à 15 h 54	13/ 4/64 à 16 h 25
29/ 8/57 à 19 h 20	6/11/61 à 23 h 18	10/ 5/64 à 0 h 35
29/ 9/57 à 0 h 16	4/ 2/62 à 09 h 30	7/ 6/64 à 18 h 52
21/10/57 à 22 h 41	6/ 2/62 à 21 h 01	4/ 8/64 à 1 h 30
18/11/57 à 09 h 52	31/ 5/62 à 05 h 52	6/ 9/64 à 19 h 55
24/11/57 à 09 h 01	26/ 6/62 à 08 h 50	3/10/64 à 12 h 43
19/12/57 à 09 h 37	3/ 7/62 à 12 h 02	1/11/64 à 03 h 20
18/ 7/58 à 2 h 21	31/ 7/62 à 15 h 45	7/12/64 à 09 h 40
17/10/58 à 15 h 09	30/ 8/62 à 23 h 40	

b) Tamanrasset Observatory

30/ 6/57 à 05 h 28	15/ 1/58 à 09 h 54	4/ 2/59 à 05 h 50
22/ 7/57 à 04 h 19	18/ 1/58 à 07 h 20	4/ 5/59 à 20 h 21
21/10/57 à 22 h 41	18/ 7/58 à 02 h 21	29/10/59 à 23 h 47
18/11/57 à 09 h 52	17/ 8/58 à 06 h 22	28/11/59 à 23 h 51
24/11/57 à 09 h 01	17/10/58 à 15 h 09	27/12/59 à 10 h 22
18/12/57 à 09 h 37	10/11/58 à 05 h 10	29/ 1/60 à 02 h 05

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