MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO DE PESQUISAS ESPACIAIS

AUTORIZAÇÃO PARA PUBLICAÇÃO
AUTHORIZATION FOR PUBLICATION

AUTORES / AUTHORS — PALAVRAS CHAVES/KEY WORDS

GEOMAGNETIC ACTIVITY

AUTORIZADA POR/AUTHORIZED BY

Marco Antonio Raupp
D.General Director

AUTOR RESPONSAVEL / RESPONSIBLE AUTHOR

R.P. Kane

DISTRIBUIÇÃO/DISTRIBUTION

- [ ] INTERNA / INTERNAL
- [x] EXTERNA / EXTERNAL
- [ ] RESTRITA / RESTRICTED

REVISADA POR / REVISED BY

Nalin B. Trivedi

CDU/UDC

550.38

DATA / DATE

27/04/87

PUBLICAÇÃO Nº / PUBLICATION NO

INPE-4069-PRE/1025

ORIGEM / ORIGIN

DGA

PROJETO / PROJECT

GEOMA

TÍTULO/TITLE

FORECASTING GEOMAGNETIC ACTIVITY

Nº DE PAG. / NO OF PAGES: 21

ULTIMA PAG. / LAST PAGE: 19

VERSÃO / VERSION: 2nd

Nº DE MAPAS / NO OF MAPS:

AUTORES/AUTHORSHIP

R.P. Kane

RESUMO-NOTAS/ABSTRACT-NOTES

A study of the daily, monthly and annual values of the geomagnetic activity index Ap for 1932 onwards and of the annual aa indices for 1868 onwards indicate that their variations had large random components. Long-term predictions were not possible from time-series extrapolations.

OBSERVAÇÕES/REMARKS

This work was partially supported by the "Fundo Nacional de Desenvolvimento Científico e Tecnológico" under contract FINEP 537/CT and published in Pure and Applied geophysics, 26:85-101, 1988.

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO DE PESQUISAS ESPACIAIS

AUTORIZAÇÃO PARA PUBLICAÇÃO
AUTHORIZATION FOR PUBLICATION

PALAVRAS CHAVES/KEY WORDS — AUTORES/AUTHORS: GEOMAGNETIC ACTIVITY

AUTORIZADA POR/AUTHORIZED BY: Marco Antonio Raupp, General Director

AUTOR RESPONSAVEL / RESPONSIBLE AUTHOR: Rajaram P. Kane — R.P. Kane

DISTRIBUIÇÃO/DISTRIBUTION:
- [ ] INTERNA / INTERNAL
- [x] EXTERNA / EXTERNAL
- [ ] RESTRITA / RESTRICTED

REVISADA POR / REVISED BY: Nalin Trivedi — Nalin B. Trivedi

CDU/UDC: 550.38

DATA / DATE: 27/04/87

PUBLICAÇÃO Nº / PUBLICATION NO: INPE-4069-PRE/1025

ORIGEM / ORIGIN: DGA

PROJETO / PROJECT: GEOMA

Nº DE PAG. / NO OF PAGES: 21

ULTIMA PAG. / LAST PAGE: 19

VERSÃO / VERSION: 2nd

Nº DE MAPAS / NO OF MAPS:

TÍTULO/TITLE: FORECASTING GEOMAGNETIC ACTIVITY

AUTORES/AUTHORSHIP: R.P. Kane

RESUMO-NOTAS/ABSTRACT-NOTES

A study of the daily, monthly and annual values of the geomagnetic activity index Ap for 1932 onwards and of the annual aa indices for 1868 onwards indicate that their variations had large random components. Long-term predictions were not possible from time-series extrapolations.

OBSERVAÇÕES/REMARKS

This work was partially supported by the "Fundo Nacional de Desenvolvimento Científico e Tecnológico" under contract FINEP 537/CT. This work is being submitted to Pure and Applied Geophysics.

1. Publication Nº	2. Version	3. Date	5. Distribution
INPE-4069-PRE/1025		Dec., 1986	☐ Internal ☒ External ☐ Restricted
4. Origin DGA/DIG — Program GEOMA			

6. Key words - selected by the author(s)
GEOMAGNETIC ACTIVITY

7. U.D.C.: 550.38

8. Title INPE-4069-PRE/1025

FORECASTING GEOMAGNETIC ACTIVITY

10. Nº of pages: 21

11. Last page: 19

12. Revised by

Nalin B. Trivedi

9. Authorship R.P. Kane

Responsible author Rajaram P. Kane

13. Authorized by

Marco Antonio Raupp
Director General

14. Abstract/Notes

A study of the daily, monthly and annual values of the geomagnetic activity index Ap for 1932 onwards indicates that, apart from an occasional 27-day recurrence tendency in the daily values, small increases in equinoxes for the average monthly values and (in general) low values during sunspot minimum, all other Ap variations are mostly random.

15. Remarks This work was partially supported by the "Fundo Nacional de Desenvolvimento Científico e Tecnológico" under contract FINEP 537/CT. This work is being submitted to Pure and Applied Geophysics.

MINISTERIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO DE PESQUISAS ESPACIAIS

PROPOSTA PARA PUBLICAÇÃO

- [ ] DISSERTAÇÃO
- [ ] TESE
- [x] RELATÓRIO
- [ ] OUTROS

IDENTIFICAÇÃO

TÍTULO: Forecasting Geomagnetic Activity

AUTOR(ES): R. P. KANE

ORIENTADOR:

CO-ORIENTADOR:

LIMITE: __/__/__ DEFESA: __/__/__ CURSO: ORGÃO:

DIVULGAÇÃO: [x] EXTERNA [ ] INTERNA [ ] RESTRITA

EVENTO/MEIO: [ ] CONGRESSO [x] REVISTA [ ] OUTROS

REV. TÉCNICA

NOME DO REVISOR: Nalin. B. Trivedi.

RECEBIDO: 21/10/86 DEVOLVIDO: __/__/__ ASSINATURA: Nalin. Trivedi.

APROVAÇÃO

NOME DO RESPONSÁVEL: José Marques da Costa

APROVADO: [x] SIM [ ] NÃO DATA: 23/10/86 ASSINATURA: [signature]

REV. LINGUAGEM

Nº: 434 PRIOR.: 1 RECEBIDO: 14/11/86 NOME DO REVISOR: Glória

PÁG.: 14 DEVOLVIDO: 19/11/86 ASSINATURA: G. Bertti

DATILOGRAFIA

OS AUTORES DEVEM MENCIONAR NO VERSO INSTRUÇÕES ESPECÍFICAS, ANEXANDO NORMAS, SE HOUVER

RECEBIDO: DEVOLVIDO: __/__/__ NOME DA DATILÓGRAFA:

Nº DA PUBLICAÇÃO: 4069 PRE/1025 PÁG.:

CÓPIAS: Nº DISCO: LOCAL:

DIRETOR

AUTORIZO A PUBLICAÇÃO: [ ] SIM [ ] NÃO __/__/__

OBSERVAÇÕES E NOTAS

Pure and Applied Geophysics

Palavras Chaves (Key words)

GEOMAGNETIC ACTIVITY

APÓS A PUBLICAÇÃO, ESTA FICHA SERÁ ARQUIVADA JUNTAMENTE COM A VERSÃO ORIGINAL

INPE 106

FORECASTING GEOMAGNETIC ACTIVITY

R. P. Kane

Instituto de Pesquisas Espaciais - INPE
C.P. 515, 12201 - São José dos Campos, SP, Brasil

ABSTRACT

A study of the daily, monthly and annual values of the geomagnetic activity index Ap for 1932 onwards and of the annual aa indices for 1868 onwards indicated that their variations had large random components. Long-term predictions were not possible from time-series extrapolations.

1 - INTRODUCTION

For low-orbiting artificial satellites, the atmospheric drag is a significant source of perturbation. The drag is dependent upon the atmospheric density, which, in turn, depends upon the temperature. However, to a lesser extent, the density is also affected by geomagnetic storms (Jacchia 1977, 1979; Barlier et al., 1978; Hedin et al., 1981). As such, information about the future behaviour of geomagnetic activity would certainly be useful. In a recent review, Feynman and Gu (1986) have discussed this problem in great detail and have considered time lags between solar and geomagnetic activity, recurrent versus non-recurrent magnectic activity, magnetic storm occurrence frequency, the solar wind and the interplanetary magnetic field. For the aa index, two methods are described, both of which need information about the possible future behaviour of the sun (sunspot number). The authors say that neither of the two methods is satisfactory. In the present communication, we explore the possibility of studying the long-term periodicities in the time-series of geomagnetic indices and extrapolating these for future.

2 - DATA

The conventional index of low and middle latitude geomagnetic activity is the 3-hourly K index introduced by J. Bartles in 1938 and reported by 12 or 13 magnetic observatories all over the world. From these, a 3-hourly planetary index K_p is calculated and reported monthly by the Institut für Geophysik at Göttingen, Germany. K_p is quasi-logarithmic, with values 0, 0^+, 1^-, 1 ... 9 and can be converted to a 3-hourly planetary amplitude a_p, which is a measure of the range of magnetic activity over a 3-hour period in 2-nanotesla units (Bartels et al., 1939). Thus,

K_p = 0	1	2	3	4	5	6	7	8	9
a_p = 0,	4,	7,	15,	27,	48,	80,	132,	207,	400 .

The mean of the eight a_p-values for a day is known as the daily Ap-index. From an improved distribution of stations and better conversion processes, Mayaud (1973) has introduced the index aa, which is available since 1868. We propose to use A_p and aa series for spectral analysis. Other indices will not be considered either because they are almost similar to these (c indices) or because they do not have long series (ring current index D_{st} and auroral indices AE, AU, AL).

3 - CHARACTERISTICS OF Ap

a) Day-to-day variability

Fig. 1 shows a plot of the daily Ap index for May 1-Oct. 9, 1982 on a 27-day calender. As can be seen, Ap values vary in a very wide range. Sometimes, large values seem to repeat after about 27 days, the solar rotation period, indicating the presence of long-lasting active regions on the sun. This behaviour is related to the occurrence of Sudden Commencement and Recurrent storms, for which Feynman and Gu (1986) have given prediction schemes which seem to be reasonably adequate. They have also given the distributions of aa (No. of days per year) for different yearly averages of aa.

b) Month-to-month variability

Fig. 2 shows the month-to-month Ap sums, starting from the solar minimum years 1932-33-34, followed by the rising solar activity years 1935-36, maximum solar activity years 1937-38-39, falling solar activity years 1940-41-42, back to solar minimum years 1943-44, followed by years of rising solar activity and so on, up to 1971-72-73-74 (Rows 1-4). In most of the cases, Ap values are larger near equinoxes (March and September). Row 5 shows the average plots (full lines) for the various categories of solar activity. The crosses represent the observed average Ap for the years 1975-76-77 and 1985 (solar minimum), 1978-79 (rising solar activity), 1980-81-82 (solar mixímum) and 1983-84 (falling solar activity). In general, equinoxes show larger Ap values but the full lines do not seem to match the crosses always, indicating that the full lines are not invariably good as predictions. The discrepancy can be as large as ±5 Ap in values of Ap ~15. Row 6 in Fig. 2 shows the average month-to-month variation for all the 43 years (1932-1974) (full lines) composed of 10 solar minimum, 8 rising, 12 maximum and 13 falling solar cycle years. The crosses represent the average of the observed values for the 11 years of the recent solar cycle (1975-1985). Discrepancies of ±3 Ap are still seen. Feymman and Gu (1986) have presented results of a detailed study of the semi-annual variation of aa indices for 1868-1967.

c) Relationship between Ap and sunspot cycle

When the sun is quiet, there are very few magnetic storms. Thus, some relationship between Ap and sunspot number R_z is expected. In Fig. 3, the top plot (full lines) shows the annual sunspot number R_z for 1932-1976 and the crosses show Ap. The other plots are occurrence frequencies (number of days per year) when Ap exceeded 15, 50, 80 and 135. These values correspond roughly to Kp = 3, 5, 6 and 7 respectively,data for which were readily available in the NGSDC Data Fact Sheet No. 1, "Some summary geomagnetic activity data 1932-1976", by M. Myers and J.H. Allen of NOAA, Environmental data service, Boulder, Colorado, USA. The full and dashed vertical lines indicate sunspot cycle minima and maxima, respectively. As can be seen, Ap values of all categories are fewest near sunspot minima; but Ap values are not most numerous near sunspot maxima. Large storms (large Ap) seem to have two maxima, one near the solar maximum and another a few years later. It is generally believed that geomagnetic activity tends to peak during the falling phase of the sunspot activity. However, such a pattern does not seem to be observed consistently. During 1932-1944, large Ap (black portion) had one broad maximum 1 to 3 years after the solar maximum (1932). During 1944-1954, there was a large Ap maximum one year before the solar maximum (1947). During 1954-1964, there were two Ap maxima, one coinciding with the solar maximum (1957) and another 3 years later. During 1964-1976, large Ap had a flat distribution. The relationship between R_z and Ap seems to be highly variable from cycle to cycle. Also, the magnitude of Ap does not seem to bear any relationship with the magnitude of R_z as can be seen from the plots in the top part of Fig. 3. Thus, the sunspot number by itself is not a clear and sure guide to the strength of geomagnetic activity. Fig. 4 shows a plot of annual Ap versus annual sunspot number with different symbols for successive solar cycles since 1932 up to 1985. The scatter indicates a lack of clear relationship. A similar plot for annual aa versus annual sunspot number by Feynman and Gu (1986) also showed a large scatter, implying a loose relationship.

d) Spectral analysis of Ap series

Since Ap has no clear relationship with the sunspot cycle, the Ap series was studied independently. The most sophisticated method for spectrum analysis is the Maximum Entropy Spectral Analysis (MESA) devised by Burg (1967) and critically studied by Ulrych and Bishop (1975). The method is superior to the Blackman and Tukey method (1958) and locates periodicities very accurately. However, it has a major drawback viz. the amplitude estimates are unreliable. Hence Kane (1977) suggested the procedure of using MESA only for locating the n periodicities T_k ($k = 1$ to n) and using these T_k in the expression:

$$f(t) = a_0 + \sum_{k=1}^{n} [a_k \text{ Sin } 2\pi \frac{t}{T_k} + b_k \text{ Cos } 2\pi \frac{t}{T_k}] + E$$

$$= a_0 + \sum_{k=1}^{n} r_k \text{ Sin } [2\pi \frac{t}{T_k} + \phi_k] + E \qquad (1)$$

where f(t) is the observed time series and E is the error term. A Multiple Regression Analysis (Johnston, 1960; Bevington, 1969) is then carried out where the best estimates of a_0, (a_k, b_k) or (r_k, ϕ_k) and their standard errors are obtained by a least-square fit. Any r_k exceeding $2\sigma_{rk}$ would normally be significant at a 95% confidence level. However, this is an a priori confidence level. In cases where the periodicities observed may not have a physical justification, Madden and Julian (1971) have pointed out the need of using the a posteriori sampling theory. Roughly this involves raising the significance level. In our case, a 2σ (95% confidence) a posteriori level seemed to be equivalent to ~3.5σ a priori level. Hence, we examined all r_k for significance at ~4σ level. For a cyclic variation of amplitude r_k, the variance works out to $(r_k^2/2)$, as obtained by an integral over complete cycles. For smaller periodicities many cycles are involved in a sufficiently large data length (e.g. T=5 in 100 years data has 20 cycles) and hence the above expression is almost exactly valid. For larger periodicities, the data length may not contain an integral number of cycles (e.g. T=30 in 100 years data) and the above expression is only approximate. The Percentage Variance Explained (PVE) by every amplitude r_k was obtained as $(50\ r_k^2/\sigma^2)$, where σ^2 = Variance of the observed f(t) series.

The Ap annual values are available from 1932 onwards i.e. 54 values up to 1985. Since the last few values are needed for checking prediction, the remaining values (less than 50) are rather few for MESA. Monthly values would be ~600, rather too many. A plot of the monthly values indicated that the lowest regular periodicity was 6 months. Fraser-Smith (1972) used Ap values for 1932-1970 (38 years) and reported peaks at 6.0, 13.1, 17.6, 49, 62, 84 and 122 months. Hence, we evaluated 3-monthly averages of Ap and used the 180 values (1932-1976) for MESA. We obtained spectra for a variety of LPEF (Length of the Prediction Error Filter). For very low LPEF (~10) only very small periodicities were detectable. As successively larger LPEF (= 20, 30, 40, 50, etc.) were used, larger periodicities were detected while the smaller periodicities remained in the some position. We used all these spectra (up to LPEF = 90, i.e. up to 50% of the data length 180) and confined ourselves to periodicities up to ~180 months i.e., 1/3 rd of the data length 540 months (180 3-monthly values) as, for such small periodicities, the errors are very small (<1%). Using all these periodicities T_k (k = 1 to n), a Multiple Regression Analysis was carried out to determine their amplitudes r_k and standard errors σ_{rk}. Some r_k were not significant et a $2\sigma_{rk}$ level. Periodicities significant at a 2σ a priori level and their amplitudes, standard errors and PVE were as follows.

Periodicities T_k		Amplitude r_k (Ap units)	Standard error σ_{rk} (Ap units)	Significance level (a priori)	Percentage Variance Explained (PVE)
Months	Years				
6.6	~0.5	0.94	±0.43	2σ	1.8
49.4	4.1	1.23	±0.44	~3σ	3.1
56.4	4.7	1.30	±0.46	~3σ	3.5
66.7	5.6	1.50	±0.45	>3σ	4.7
91.5	7.6	1.68	±0.44	~4σ	5.8
129.4	10.8	2.86	±0.44	>6σ	16.9
172.5	14.4	1.72	±0.44	~4σ	6.1

Thus, four periodicities had significances exceeding 3σ (a priori) or ~2σ (a posteriori). However, the Percentage Variance Explained by these is rather small. The most prominent periodicity is ~11 years, but it explains only ~17% Variance. Thus, the series seems to have a very large random component. Also, from basic data points of 3 months, the 6 months periodicity estimate will not be very reliable.

Using these significant r_k and their corresponding ϕ_k (not given here) in the right-hand side of equation (1), one could obtain the expected values of f(t). Fig. 5 shows a plot of the original f(t) series of Ap (full lines) and the expected values (crosses). For camparison, the 3-monthly average sunspot number is also plotted (dashed lines). The following may be noted:

(i) The observed and expected values of Ap match only in a general way. Near sunspot minimum years (1933, 1944, 1954, 1964, 1975), both show low values. However, in other years, there is often considerable divergence. In particular, the ups and downs of the observed values in alternate values (which, in this case, represent the 6 month periodicity) are very prominent in some years and almost missing in some other years, indicating that the semiannual wave is very unstable. Since the expected values (crosses) are based on stable (constant amplitude and phase) periodicities, the ups and downs are not reproduced very well.

(ii) The real test of this exercise would be in checking the fit for independent data, after 1976. In the lowest part of Fig. 5, the vertical line marks the end of the series (1976) utilised for spectral analysis. After 1976, the big dots joined by full lines are the observed values up to 1985 and the crosses are the predictions. The maching is rather poor. In particular, observed Ap was very large in 1978 and 1982 while the expected values were low or medium.

We conclude, therefore, that regular, stable periodicities play only a minor role in the Ap series and a major part is of random origin and/or due to transient periodicities. As such, the predicted values after 1985 (crosses in Fig. 5) are not reliable.

To reduce the randomness, we evaluated running averages over 4 consecutive 3 monthly averages. Thus, a smoothed series of annual averages, with centering 3 months apart, was produced. The 178 values (1932-1976) were subjected to MESA. Periodicities obtained and their amplitudes were:

Periodicity T_k (Years)	Amplitude r_k (Ap units)	Standard error σ_{rk} (Ap units)	Significance level (a priori)	Percentage Variance Explained (PVE)
2.8	0.71	±0.32	>2σ	1.6
4.2	1.14	±0.32	3.5σ	4.1
4.7	0.81	±0.32	>2σ	2.1
5.3	1.27	±0.32	~4σ	5.1
7.5	1.82	±0.32	>5σ	10.4
10.5	2.72	±0.32	>8σ	23.3
14.2	1.54	±0.32	>4σ	7.5

Many periodicities are significant above a 3.5σ a priori i.e. 2σ a posteriori level, contributing a Percentage Variance Explained (PVE) of ~50%. Thus, even after so much smoothing, 50% of the Variance remains unexplained and has to be attributed to a random component.

Fig. 6 shows a plot of the observed and expected values for this smoothed series. The matching is better than in the earlier less smoothed series. However, the matching of the independent data (1976 onwards) is not satisfactory, particularly in 1978 and 1982 when observed Ap values were very large and in early 1980 when observed Ap was very low (at sunspot maximum!).

Using an approach based upon autoregression linear prediction models (Makhoul, 1978), Lopes et al. (1985) used Ap data for 1945-1968 and predicted Ap for 1968 onwards. Fig. 7 reproduces their results. Annual sunspot number is also shown. As can be seen, the $\pm\sigma$ limit indicated by their analysis is very large (~$\pm$8 Ap units), indicating a large random component.

e) Spectral analysis of aa series

Fig. 8 is a plot of annual values of the sunspot number R_z, Ap index, the aa index and the ring current Dst index. For 1932 onwards, Ap and aa index variations seem to be identical. As pointed out by Feynman and Gu (1986), the Dst index is similar to the aa index except for 1973, 1974, 1975 and 1982 when aa as well as Ap were large. Since Dst series is short, we will not consider it here. In the aa series, a conspicuous feature is the rising trend from about 1900 to 1960. Feynman and Crooker (1978) say that the aa series looks as if an 11-year cycle is supported on a long-term rise which has about the same amplitude as the 11-year cycle. Feynman (1982) and Sargent (1982) have suggested methods to evaluate the trends. However, as mentioned by Feynman and Gu (1986), both methods need an educated guess about the future behaviour of the sun (sunspot number) which may not be always accurate. Using MESA, we obtained periodicities T = 2.1, 2.3, 2.5, 2.8, 3.1, 3.4, 3.9, 4.3, 5.5, 6.8, 8.2, 10.2, 12.3, 16.2, 23.4, 28.2 and 103.5 years. Some of these (underlined) are the same or nearly the same as reported by Currie (1976) by a similar analysis of aa series by MESA. In place of our T = 10.2 and 12.3, Currie reported a broad peak at T = 11.5. We obtained an additional peak at T = 28.2 (besides T = 23.4 which is similar to Currie's T = 22.9). In higher periodicity, Currie reported T = 79 years while we obtained T = 104 years. In this range, periodicity determination is not very accurate. But, from Fig. 8, a half wave of ~55 years is noticed (1900-1955). Thus, T = 104 years could have been more realistic than T = 79 years. However, from 1960 onwards, a fall occurred only up to 1964. Later, the aa trend seems the have turned up again. Thus, this long-term periodicity (Currie's 79 years or ours 104 years) does not seem to be reliable. Currie did not evaluate the amplitudes of these periodicities. A Multiple Regression Analysis showed that many of these periodicities were not significant at a 2σ (a priori) level. Nevertheless, we used all these periodicities for prediction. Fig. 9 shows the results. In the first row, full lines represent the observed values and crosses and dashes represent the expected values, for 1868-1938. In the second row, these are continued for 1938 up to date and further. Only data for 1868 to 1967 (100 years) were used for MESA. The match between observed and expected values is reasonably good for 1868-1967. However, for independant data (big dots for 1968-1986), the match is not good. The observed values for 1973-76 and 1982-86 are much larger than the expected values. Thus the prediction failed.

In row 3, observed data for 1938 onwards are repeated. The expected values are obtained by using T = 4.32, 5.50, 10.23, 12.16, 23.44, 28.18 and 103.5 years, all which were significant at a 2σ (a priori) level and together explained 72% of the Variance.

The amplitudes were as following:

Periodicities (years)	Amplitudes rn (aa units)	Significence level (a priori)	Percentage Variance Explained (PVE)
4.3	1.1 ± 0.55	2.0 σ	1.8
5.5	1.3 ± 0.55	2.4 σ	2.4
10.2	2.1 ± 0.55	3.8 σ	6.3
12.2	2.6 ± 0.55	4.7 σ	9.9
23.4	2.4 ± 0.55	4.4 σ	8.5
28.2	2.2 ± 0.55	4.0 σ	7.3
103.5	4.9 ± 0.55	8.9 σ	35.7

The match between observed and expected values is still poor.

In row 4, only T = 10.23, 12.16, 23.44, 28.18 and 103.5 years are used for obtaining the expected values and together explain 68% variance. The match is still poor. It may be noted that a large percentage of variance (36%) is explained by T = 103.5 alone.

We conclude, therefore, that this method of extrapolation does not yield useful predictions.

4 - CONCLUSIONS AND DISCUSSION

A spectral analysis of the Ap and aa index series reveals many significant periodicities. However, extrapolations from the same do not yield good predictions. Thus, satellite planners will probably not have very reliable estimates of the future geomagnetic activity. Satellites disappearing prematurely or surviving far beyond their expected life time could be a routine feature.

In a recent communication, Kane and Trivedi (1985) analysed the annual sunspot number series and found that whereas some periodicity splitting of the 11 year cycle and some other periodicities were noticed, the predictions were unrealiable. In this paper, a similar result is obtained for Ap and aa indices. It seems that the only reliable occurrence is the quietening of the sun approximately every 11 years. All other solar activities, including the one responsible for geomagnetic storms, seem to occur in a more or less random manner. However, on short-term basis, predictions like those outlined by Feynman and Gu (1986) should be of some utility.

The periodicities obtained here by a spectral analysis of Ap and aa indices are in rough agreement with the analysis of Fraser-Smith (1972), Mayaud (1972), Currie (1976) and Courtillot et al. (1977). Some periodicities seem to be harmonics of the fundamental solar magnetic cycle (SMC, 22 years) and the fundamental solar cycle (SC, 11 years). However, the stability of these periodicities have been doubted by the above authors also.

5 - ACKNOWLEDGEMENTS

This work was partially supported by FNDCT, Brazil under contract FINEP 537/CT.

REFERENCES

BARLIER, F., BERGER, C., FALIN, J.L., Kockarts, G. and THUILLIER, G. (1978) A thermospheric model based on satellite drag data, Ann. Geophys., 34, 9-24.

BARTELS, J., HECK N.H. and JOHNSTON H.F. (1939) The three-hour-range index measuring geomagnetic activity. J. Geophys. Res. 44, 411.

BEVINGTON, P.R. (1969) "Data reduction and Error Analysis for the Physical Sciences", McGraw Hill Book Co. New York, pp. 164-176.

BLACKMAN, R.B. and TUKEY, J.W. (1958) "The measurement of power spectra", Dover, New York.

BURG, J.P. (1967) Maximum Entropy Spectral Analysis. Paper presented at the 37th meeting, Soc. of Explor. Geophys., Oklahoma City, Oklahoma, October.

COURTILLOT, V., LE MOÜEL, J.L. and MAYAUD, P.N (1977) Maximum entropy spectral analysis of the geomagnetic activity index over a 107 year interval, J.Geophys.Res., 82, 2641-2649.

CURRIE, R.G. (1976) Long period magnetic activity, 2 to 100 years, Astrophys. Space Sci., 39, 251-254.

FEYNMAN J. and CROOKER N.U. (1978) The solar wind at the turn of the century, Nature 275, 626.

FEYNMAN J. (1982) Geomagnetic and solar wind cycles 1900-1975, J. Geophys. Res. 87, 6153-6162.

FEYNMAN J. and GU X.Y. (1986) Prediction of geomagnetic activity on time scales of one to ten years, Rev. Geophys. 24, 650-666.

FRASER-SMITH, A.G. (1972) Spectrum of the geomagnetic activity index Ap, J. Geophys. Res., 77, 4209-4220.

HEDIN, A.E., SPENCER, N.W. and MAYR, H.G. (1981) Semiempirical Modeling of thermospheric magnetic storms, J. Geophys. Res., 86, 3515-3518.

JACCHIA, L.G. (1977) Thermospheric temperature, density and composition: New models, Special Report 375, Smithsonian Astrophys. Obser., Cambridge, Mass. March.

JACCHIA, L.G. (1979) CIRA 1972, recent atmospheric models, and improvements in progress, Space Res. XIX, 179-192.

JOHNSTON, J. (1960) "Econometric methods", McGraw Hill Book Co. New York, pp. 134-135.

KANE, R.P. (1977) Power spectrum analysis of solar and geophysical parameters, J. Geomag. Geoelect. 29, 471-495.

KANE, R.P. and TRIVEDI, N.B. (1985) Periodicities in sunspot numbers, J. Geomag. Geoelect. 37, 1071-1085.

LOPES, R.V.F., KUGA, H.K. and CARRARA, V. (1985) Solar flux and Geomagnetic activity prediction, Proc. Second IASTED Int. Conf. on Telecommunication and Control, pp. 338-341, Dec. 10-13, 1985, Rio de Janeiro, Brazil.

MADDEN, R.A. and JULIAN, P.R. (1971) Detection of a 40-50 day oscillation in the zonal wind in the Tropical Pacific, J. Atmos. Sci., 28. 702-708.

MAKHOUL, J. (1978) Linear prediction: a tutorial review. In: Childers D. "Modern Spectrum Analysis", N. York, John Wiley, pp. 99-118.

MAYAUD, P.N. (1973) A hundred year series of geomagnetic data 1868 -1967, indices aa, storm sudden commencements. IAGA Bull. 33.

SARGENT H.H. (1982) Geomagnetic implications of sunspot cycle 22 forecasts. Proc. Workshop on Satellite Drag (ed. J.A. Joselyn) p. 144. NOAA, Boulder, Colo.

ULRYCH, T.J. and BISHOP, T.N. (1975) Maximum entropy spectral analysis and auto-regressive decomposition, Rev. Geophys. Space Phys., 13, 183-200.

CAPTIONS FOR FIGURES

Fig. 1 - Daily Ap index for six consecutive solar rotation periods (each of 27 days) starting from May 1, 1982 and ending in Oct. 9, 1982.

Fig. 2 - Month-to-month average variation of Ap (full lines) for groups of years of solar minimum, rising solar activity, solar maximum and falling solar activity for successive cycles (Row 1-4) for 1932-1974. Row 5 is the average of rows 1-4, for number of years as indicated. Row 6 is the average of the four plots in Row 5. In Row 5 and 6, the crosses represent values for 1975-1985, the recent solar cycle.

Fig. 3 - Top: Annual mean sunspot number R_z (full lines) and Ap (crosses and dashes) for 1932-1976. Other curves show the yearly occurrence frequency (in days) of Ap exceeding 15, 50, 80 and 135. Ap exceeding 135 is shown black.

Fig. 4 - Annual Ap versus annual sunspot number. Different symbols represent different solar cycles.

Fig. 5 - Three-month averages of Ap (full lines) and the sunspot number R_z (dashed lines). The crosses represent expected Ap values, using the significant periodicities obtained by spectrum analysis of Ap (1932-1976). For 1977-1985, big dots joined by full lines are observed Ap values, to be compared with the crosses. After 1985, the crosses represent predictions for future.

Fig. 6 - 12-month running averages (3 months apart) of Ap (full lines) and the sunspot number R_z (dashed lines). Crosses represent expected Ap values.

Fig. 7 - Monthy values of Ap for 1945-1985 and the predictions with $\pm\sigma$ standard deviation limits for 1968 onwards, calculated by Lopes et al. (1985).

Fig. 8 - Annual values of the sunspot number R_z, the geomagnetic indices Ap and aa and the ring current index D_{st}. For aa, the dashed line indicates long-term periodicity or trend.

Fig. 9 - Observed values of the annual aa index (full lines) and values expected (crosses and dashes) using various periodicities as indicated, for 1868-1938 in Row 1 and 1939-2000 in Rows 2, 3, 4.

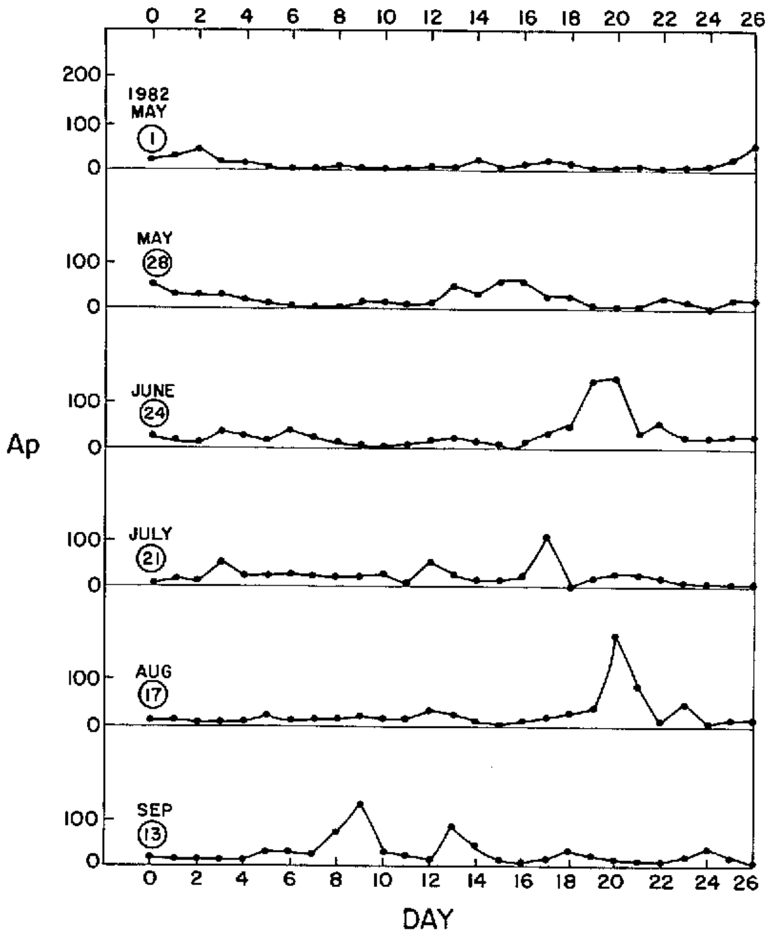

0
2
4
6
8
10
12
14
16
18
20
22
24
26
200
100
0
1982
MAY
1
MAY
28
JUNE
24
JULY
21
AUG
17
SEP
13
Ap
DAY

Fig. 1

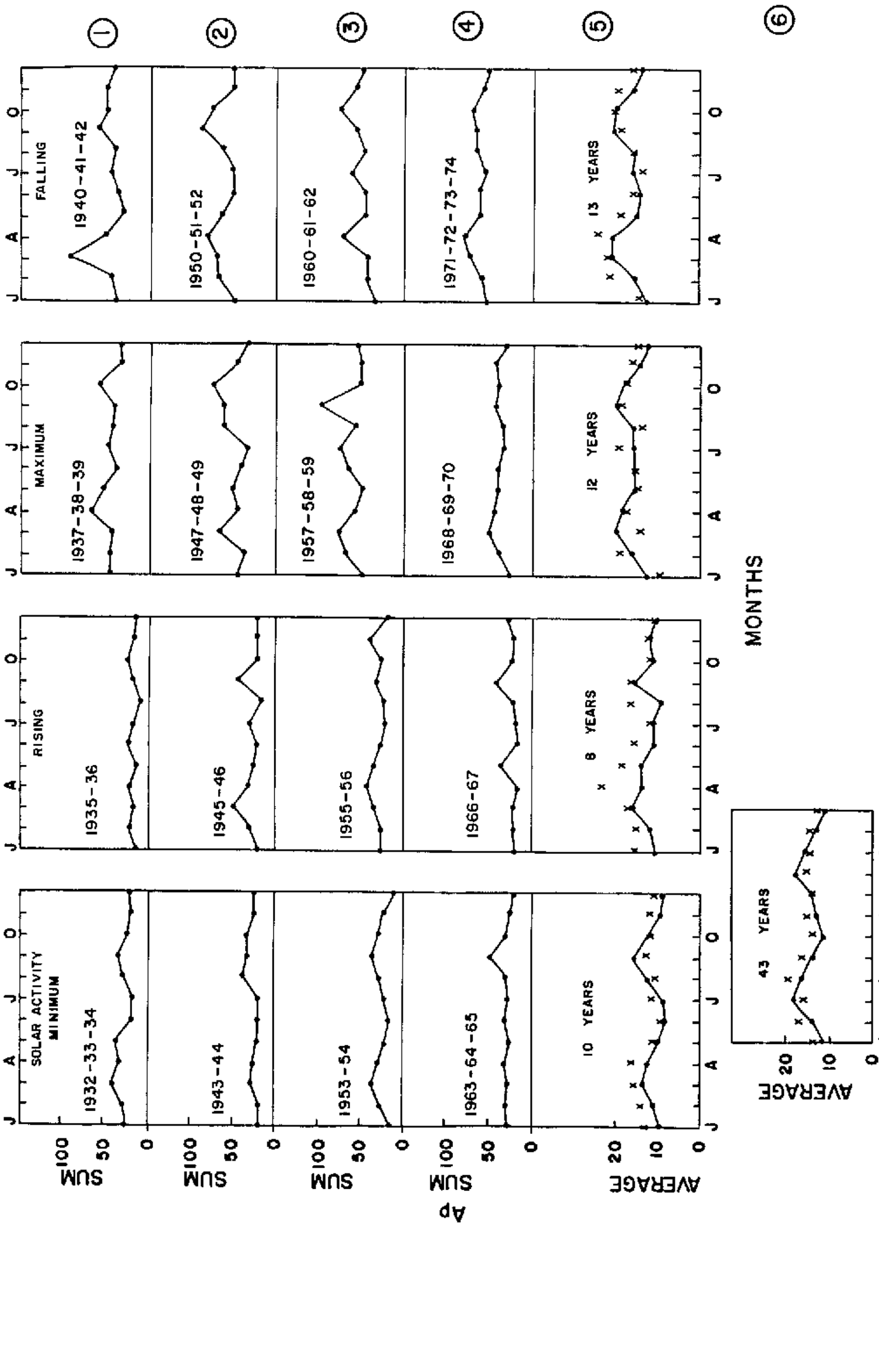

SOLAR ACTIVITY MINIMUM
RISING
MAXIMUM
FALLING
1932-33-34
1943-44
1953-54
1963-64-65
10 YEARS
1935-36
1945-46
1955-56
1966-67
8 YEARS
1937-38-39
1947-48-49
1957-58-59
1968-69-70
12 YEARS
1940-41-42
1950-51-52
1960-61-62
1971-72-73-74
13 YEARS
43 YEARS
SUM
AVERAGE
Ap
MONTHS
J A J O
1 2 3 4 5 6

Fig. 2

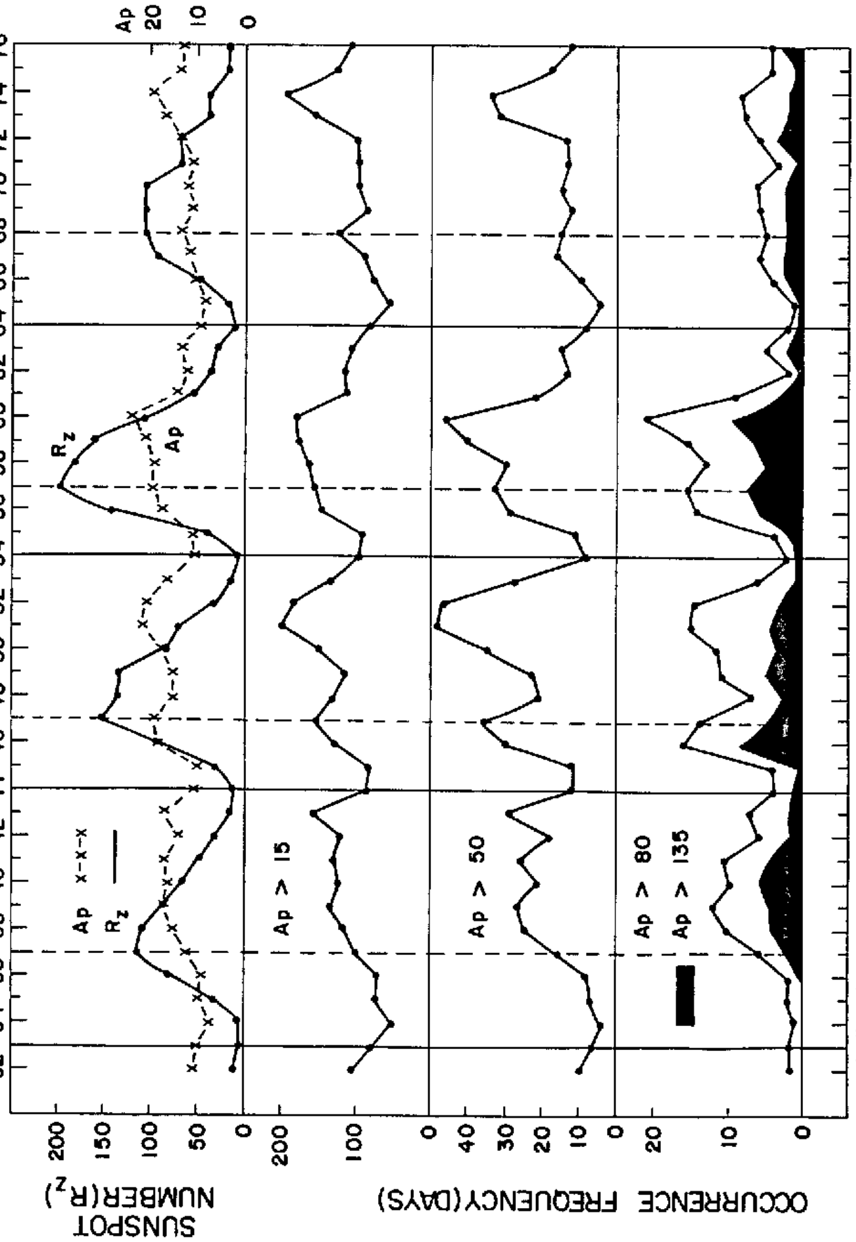

SUNSPOT NUMBER (R_z)
OCCURRENCE FREQUENCY (DAYS)
YEAR
Ap x-x-x
R_z
Ap > 15
Ap > 50
Ap > 80
Ap > 135

Fig. 3

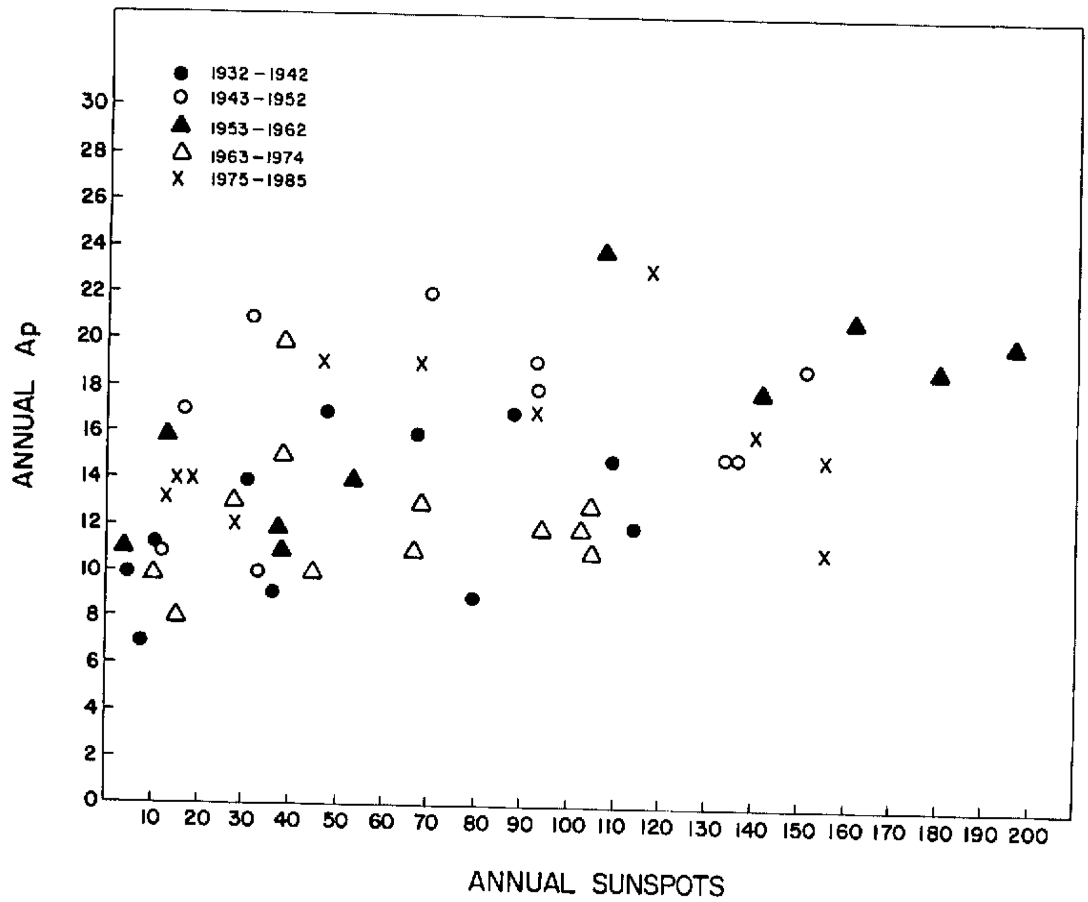

1932 - 1942
1943 - 1952
1953 - 1962
1963 - 1974
1975 - 1985
ANNUAL Ap
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
ANNUAL SUNSPOTS

Fig. 4

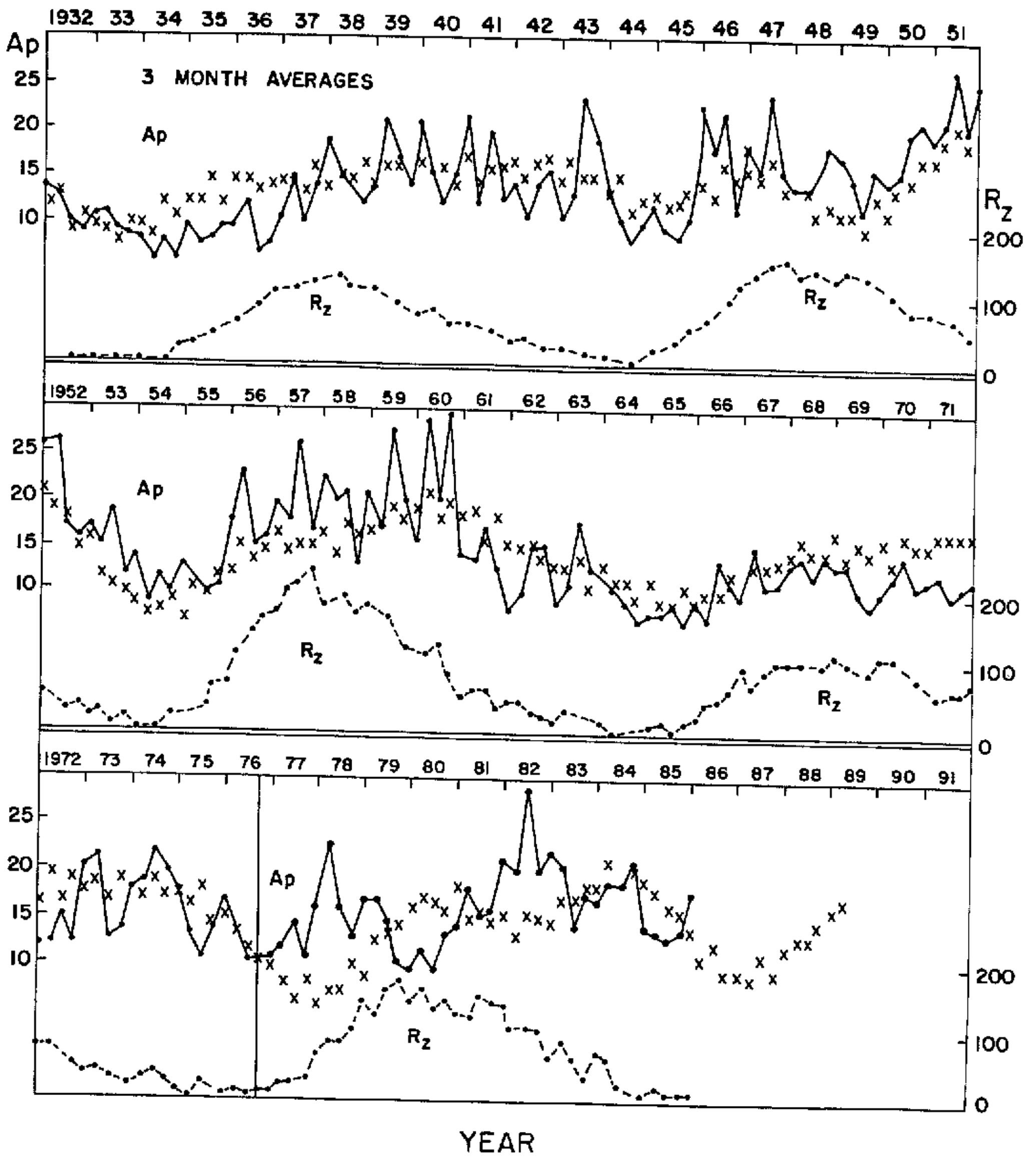

3 MONTH AVERAGES
Ap
Rz
1932 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
1952 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71
1972 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91
25
20
15
10
200
100
0
YEAR

Fig. 5

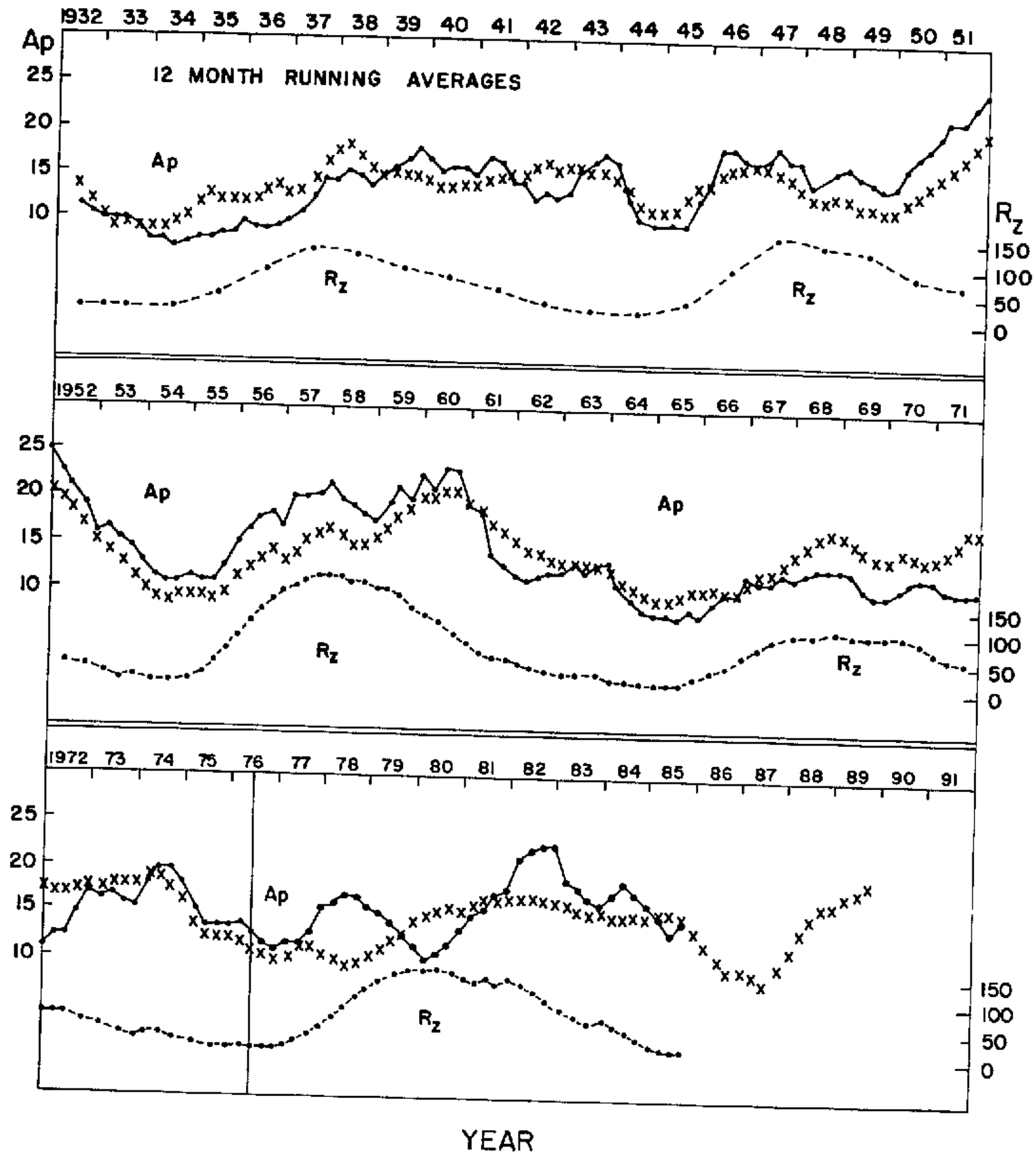
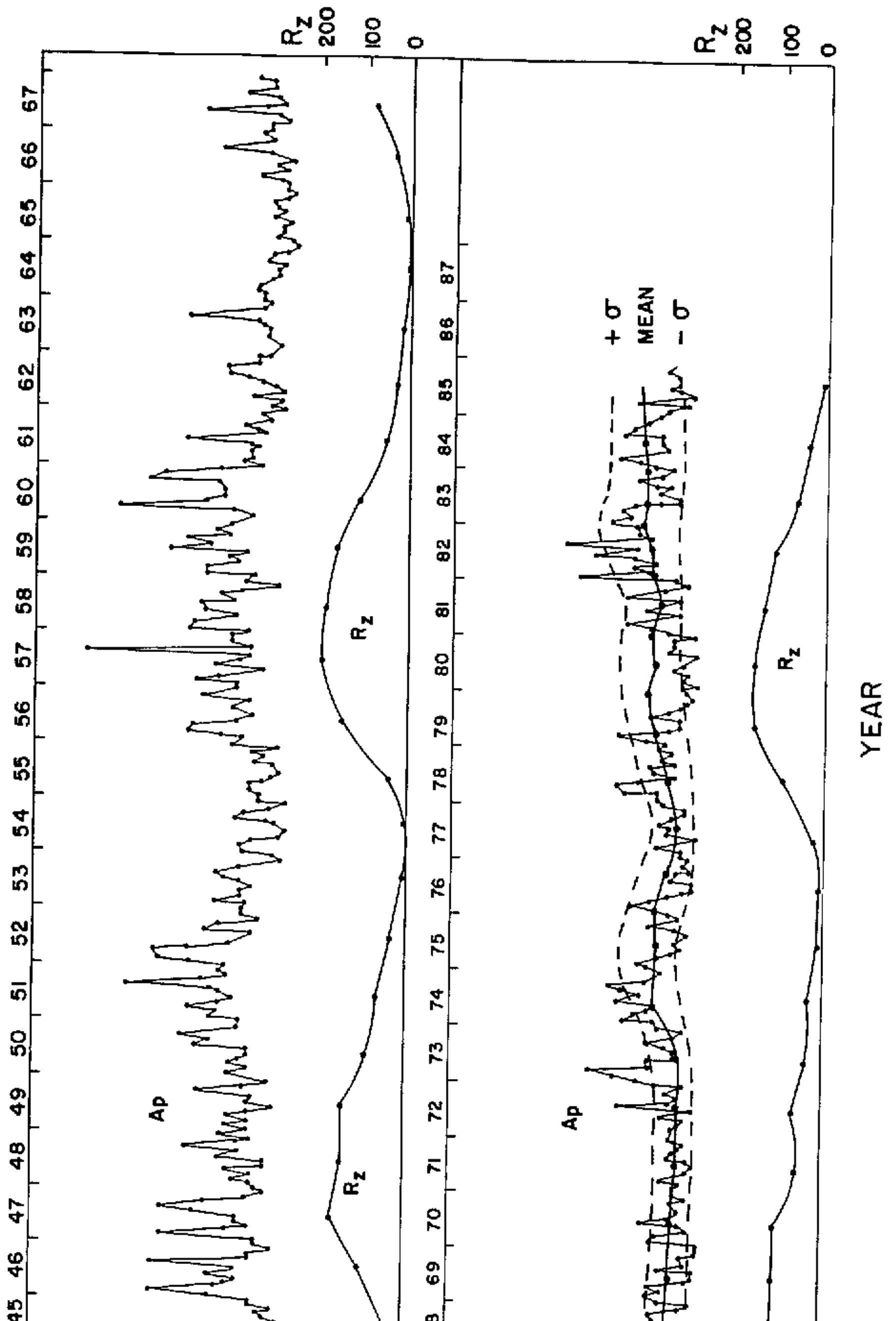

12 MONTH RUNNING AVERAGES
Ap
Rz
1932 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
1952 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71
1972 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91
25 20 15 10
150 100 50 0
YEAR

Fig. 6



1945
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
Ap
R_z
+σ
MEAN
−σ
YEAR

Fig. 7

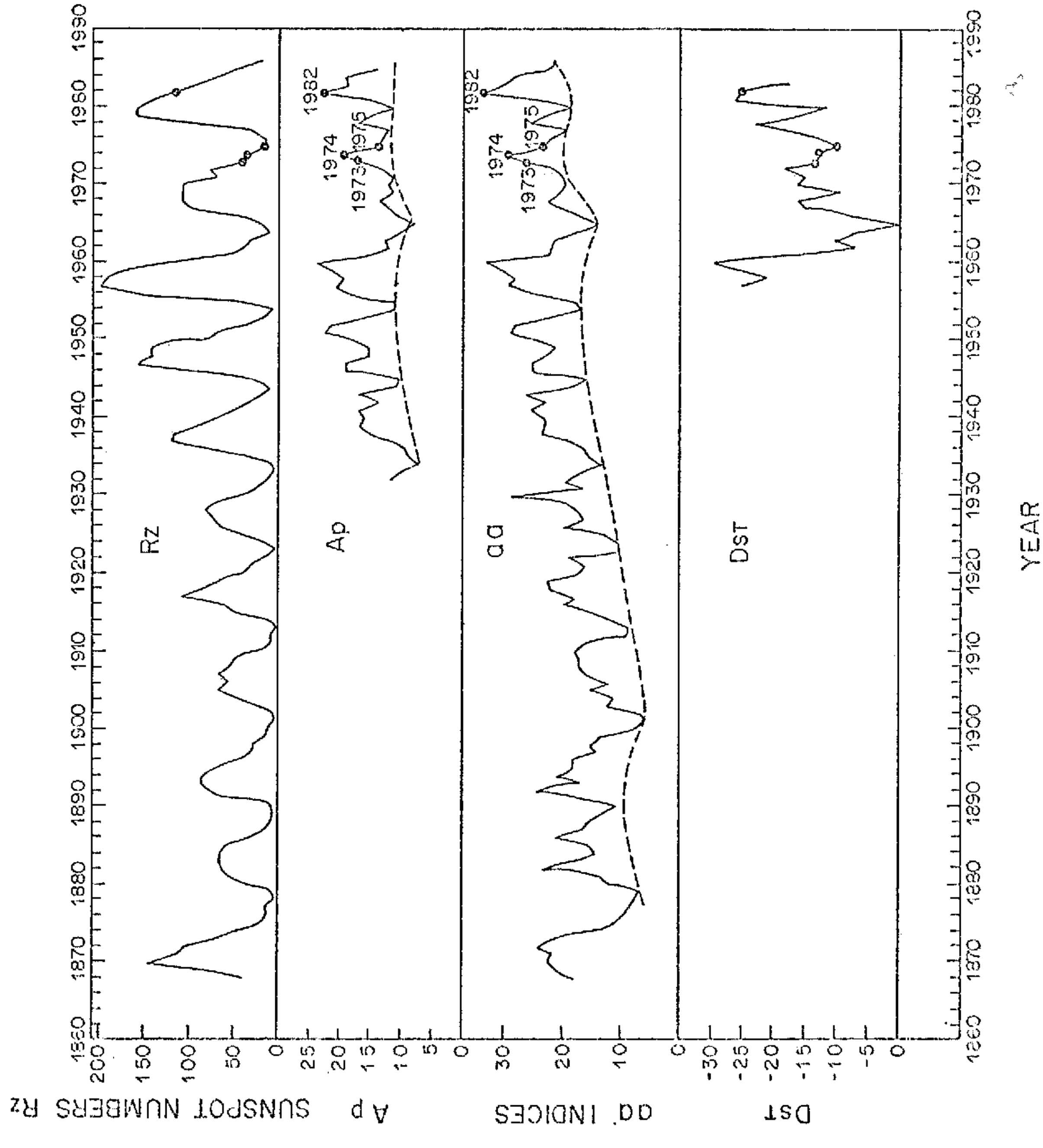

SUNSPOT NUMBERS Rz
Rz
A p
Ap
aa' INDICES
aa
Dst
1982
1974
1973
1975
YEAR

Fig. 8

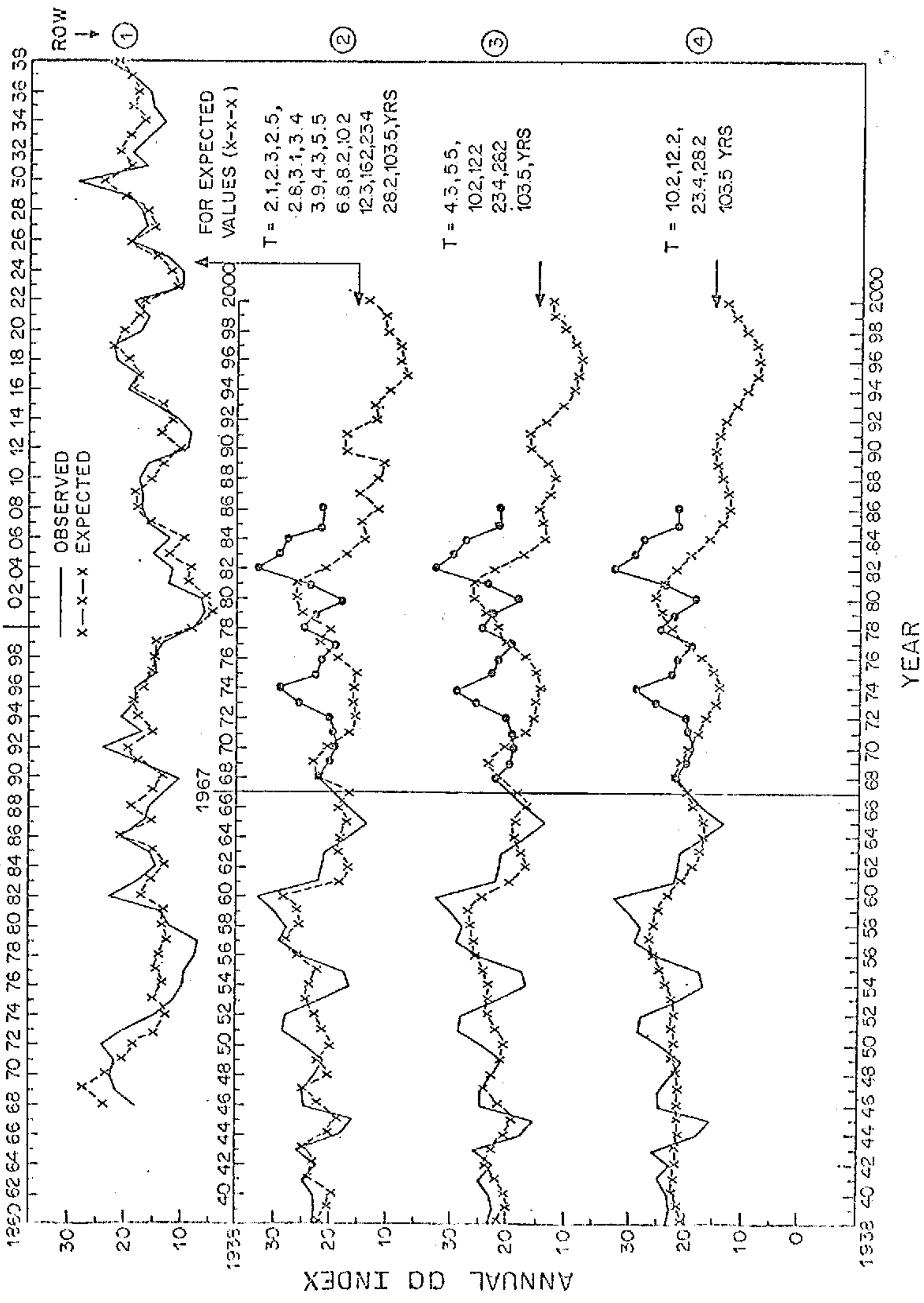

ROW
OBSERVED
X—X—X EXPECTED
FOR EXPECTED VALUES (X-X-X)
T = 2.1,2.3,2.5, 2.8,3.1,3.4 3.9,4.3,5.5 6.8,8.2,10.2 12.3,16.2,23.4 28.2,103.5,YRS
T = 4.3,5.5, 10.2,12.2 23.4,28.2 103.5,YRS
T = 10.2,12.2, 23.4,28.2 103.5 YRS
1900
1967
ANNUAL QQ INDEX
YEAR

Fig. 9