PERIODICITIES IN THE OCCURRENCE OF AURORA AS INDICATORS OF SOLAR VARIABILITY

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ABSTRACT

A compilation of records of the aurora observed in China from the Time of the Legends (2000 - 3000 B.C.) to the mid-18th century has been used to infer the frequencies and strengths of solar activity prior to modern times. A merging of this analysis with auroral and solar activity patterns during the last 200 years provides basically continuous information about solar activity during the last 2000 years. The results show periodicities in solar activity that contain average components with a long period (∿412 years), three middle periods (∿38 years, ∿77 years, and ∿130 years), and the well known short period (∿11 years).

Introduction

The use of historical auroral records to infer secular and quasi-periodic variations of the sun has received considerable attention in the last decade (Eddy, 1976; Feynman and Silverman, 1980; Siscoe, 1980). In China, beginning in 1974, a comprehensive study was initiated to document the rich, but often misinterpreted, observations of auroral displays contained in ancient records from China, Korea and Japan. Some earlier attempts to describe aurorae in Japan (Matsushita, 1956) have been made, and a chronology for aurorae in the Orient was prepared by Keimatsu (1965, 1976) and used to infer that the geomagnetic dipole axis might have been inclined towards China in the 11-12th centuries A.D. (Keimatsu et al., 1968).

In preparing a chronology of auroral displays for ancient times, it is possible to confuse passages from ancient texts that deal with meteor showers, comets, meteorological phenomena, lightning, novae and even Earthquakes with entries that truly pertain to the aurora. The chronology prepared by Keimatsu (1965) appears to include a very large number of such non-auroral events. The methods required to document a reliable database of auroral records in the Orient during ancient times have been described by Dai and Chen (1980a). The preparation of a new chronology for such events (Dai and Chen, 1980b) and its use to infer solar variability (Dai and Chen, 1980c) over extended time intervals have now been completed. In this brief paper we wish to summarize a set of preliminary results that deal with the occurrence frequencies and intensities of aurora during the period 212 B.C. to 1968 A.D., and their implications for solar variability.

Analysis

Dai and Chen (1980a, b) examined ancient records of the aurora in the East and established a chronology of 929 occurrences of aurorae from the Time of the Legends (2000-3000 B.C.) to 1747 A.D. These included 585 observations recorded in China, 294 in Korea and 50 in Japan. With this chronology added to the observations between 40^o-50^o latitude contained in the compilation prepared by Link (1962, 1964) from Western records, Dai and Chen (1980c) prepared a combined distribution plot of the number of nights in Oriental and Occidental historical times (from 222 B.C. to 1747 A.D.) when the aurora occurred. The resultant occurrence frequency diagram for 1300 separate auroral observations from middle to lower latitudes provided basically continuous information about solar activity during the last 2000 years. Dai and Chen (1980c) established a set of selection criteria to designate a series of "upper extremal years (UEY's)" and "lower extremal years (LEY's)" from these data, following a basic assumption that the period between two successive UEY's could not be shorter than 5 years, nor longer than 18 years. Once the UEY's were determined, additional analyses were performed to characterize the strengths of these years of peak auroral activity. To do this, the past 2000 years were divided into four major auroral epochs (prior to 400 A.D., 400-1050, 1050-1750 and 1750-1968) during which the historical records of aurora were essentially consistent and comparable. Within each epoch, specific criteria were established that used occurrence rates, observing latitudes, morphology types and luminosities to assign one of seven designations for the strength of each UEY. The strength criteria established for each of the first three epochs were related to the mean sunspot numbers used to specify the UEY strengths in the modern epoch in order to arrive at a uniform and consistent scale to guage overall solar variability by the auroral UEY strength patterns. The results of this analysis appear in Figure 1.

Discussion

The results used to arrive at Figure 1 showed that during the 1967-year period from 217 B.C. to 1750 A.D., that is, during the three ancient auroral epochs defined above, there were 173 upper extremal years (UEY's) of auroral activity that can be used to define 172 separate solar activity cycles. The durations of those cycles fell between 6 and 18 years, with a mean period of 11.4 years. Statistical analyses of the 172 cycles showed that 84% had periods of 7-14 years, 55% between 10-13 years, and only a few percent with 6 or 18 year periods. The mean period of 11.4 years may therefore be taken to describe the Short Period of solar activity.

The time series of UEY strength levels given in Figure 1 show that five "First Strong Years" (designated as F-years) occurred in 103 B.C., 305 A.D., 707, 1128 and 1957. These yield separations of 408, 402, 421, 428 and 401 years, respectively. The mean value of 412 years may be taken as an estimate of the Long Period of solar activity.

In arranging the Long Periods beneath each other in Figure 2, several similarities emerge between the segments:

1) After each F-year, there is a neighboring "Second Strong Year" (S-year). The intervals between them are 88, 95, 55, 77 and 70 years, respectively, with an average spacing of 77 years.

2) Prior to an F-year, there is a "Third Strong Year" (T-year). The spacings between the T-years and F-years are 139, 127, 113, 151 and 120 years, respectively, with an average of 130 years.

3) In examining the overall pattern in Figure 1, there are 57 peaks between 217 B.C. and 1957 A.D., corresponding to an average of one peak every 38 years. Within each of the 412 year Long Period segments in Figure 1, there are 8, 11, 9, 11 and 12 peaks, respectively, again showing that about every fourth Short Period cycle (∿11 years) becomes a local peak.

The Strength of Solar Activity

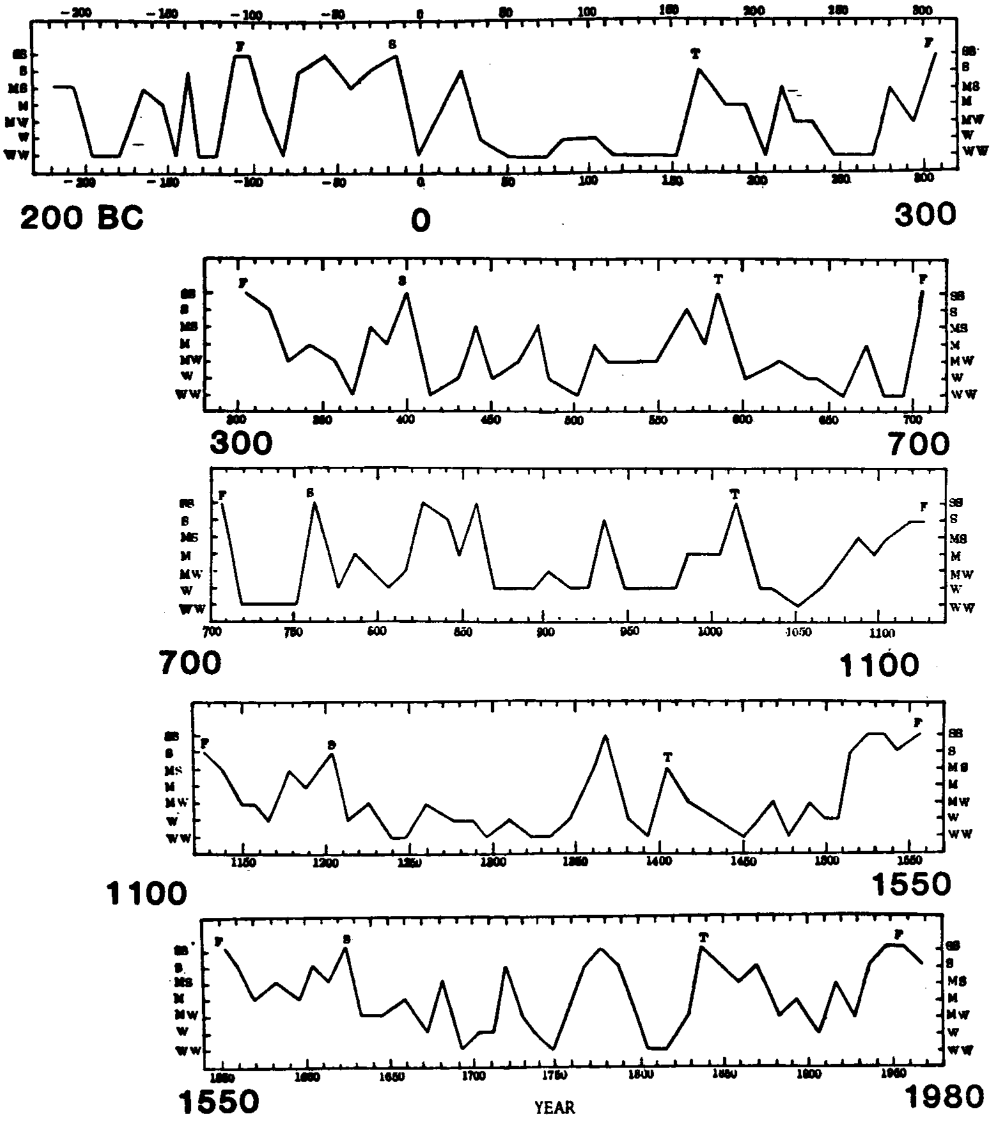

Figure 1. The strength of solar activity from 217 B.C. to 1968 A.D. determined from an analysis of chronologies of auroral occurrence patterns observed in the Orient (Dai and Chen, 1980a, b) and in Europe (Link, 1962, 1964). The strength designations from very strong (SS), to moderate (M), to very weak (WW) are intended to portray sunspot number values over the 2000 year period according to the following key: SS (>145), S (111-145), MS (96-110), M (81-95), MW (71-80), W (60-70), WW (<60).

Efforts to use historical auroral observations to search for the existence of periodicities in solar activity have thus yielded average components with a Long Period (∿412 years), three Middle Periods (∿38 years, ∿77 years and ∿130 years), and the well-known Short Period (∿11 years). Such signatures of solar-terrestrial activity patterns may well be a major source for learning about solar activity itself, as discussed in detail by Eddy (1976), Siscoe (1980), Feynman and Silverman (1980) and Feynman (1982).

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