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Some Topics on the Auroras in Middle and Low Latitudes

Zhu Gangkun(朱岗崑) and Hong Minghua(洪明华)
Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100101, China

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Abstract This paper consists of the following topics: (1) Significance of observing lower-latitude auroras. (2) Different kinds of atmospheric luminosity. (3) Chronological catalogues and maps of isochasms for auroral visibility. (4) Analysis of archaeo-auroras in low latitudes during earlier centuries. (5) Aurora observing studies since International Geophysical Year (IGY). (6) Concerning prediction of auriora occurrence.
Key words low-latitude auroras, archaeo-auroras, IGY and post IGY era, prediction methods.

1 Significance of observing lower-latitude auroras

Early in 1957 Prof. S. Chapman, then the Chairman of Scientific Committee of the International Geophysical Year (CSAGI), published a paper in Nature, recommending the adequate observation of the most widespread and intense auroras in the world. The aurora is one of the most spectacular natural phenomena; it has intrigued mankind since ancient times. As well known nowadays, the formation of aurora is primarily due to interactions among geomagnetic field, solar wind charged particles and upper atmosphere of the earth. Indeed, people living in the polar region may frequently enjoy seeing its beauty and splendor, but human in middle and low latitudes could not be possible to do so, except in very rare occasions. On the other hand, if an aurora is seen, its interest and rarity are greatest in the lowest latitudes. From the scientific point of view we think the enforced observation of low-latitude auroras may benefit many topics of much significance. The following are some useful examples: (a) Comparisons of archaeo-auroras observed in the Occident and Orient may trace the archaeo-secular variation of the geomagnetic field or the wandering of virtual geomagnetic Pole (cf. M. Keimatsu *et al*. 1968). (b) Visual auroras at low latitudes may indicate changes in the size of the auroral oval and test of aurora conjugacy (cf. Tschu and Hong 1999). (c) The aurora is distinctive in color and form, time-space of incidence, and in its many associations with other phenomena, such as solar wind, sunspots and coronal mass ejects, magnetic storms and ionospheric storms. So the world-wide observations of auroras are very useful in the associated studies of statistical analyses and physical processes, e.g. three adiabatic invariants (cf. A. Egeland *et* *al*. 1973).

2 Different kinds of atmospheric luminosity.

Generally, there are two different classes of luminosities according to the light coming from outside of or being generated in the atmosphere, The former includes rainbows, haloes and the beautiful colors of twilight and dawn; the light coming from outside the atmosphere is usually modified by the air or its dust or cloud particles. Zodiacal light seen post-twilight or predawn may be also included in this class. The latter include lightening, meteors and the aurora and airglow. Among them, visual discrimination between airglow and weak auroras may sometimes be difficult; but their origins are quite different. The night airglow is produced by chemical reactions in the upper atmosphere, energized by sunlight absorbed during the daytime. The aurora is produced by the entry into the magnetosphere and the top atmosphere of charged particles with energy from less than 100 eV to a few 100 keV.

Now turning to the observation of auroras chiefly at polar regions (Tschu and Hong 1999). Results of watching aurora borealis are rather enormous, thanks to the efforts of many polar explorers and scientists, we have gained knowledge about the variety of shapes, colors, structures, and the movements of the aurora. Aurora forms may be classified into arcs, bands, patches, veils and rays, easily detected by eyesight or photograph. By triangulation on auroral photographs C. St? rmer (1874-1957) clearly showed auroras heights averaged 105-130 km and as low as 65 km and as high as 965 km. Through the spectroscopic works due to A. J. ? ngstrom and L. Vegard, the aurora spectrum consists of many lines and bands of different colors with dark spaces among them. Also aurora colors vary with height: below 96.5 km of height due to higher air density resulting blue and red band of nitrogen molecules; between the height of 96.5-241 km, primary is the green line 5577 Å of oxygen atom, and higher than the height of 241 km, the red line 6300 ? being significant. As regards the study of aurora australis, its history is much later than that of aurora borealis. Earlier works are mainly due to many Antarctic explorers. Since the beginning of the IGY of 1957- 1958 the great increase in Antarctic observing stations (29) by different countries (7) led to more auroral research.

Either at polar regions or at middle and low latitudes, the way of observing auroras depends on human's eyesight nearly for hundred and thousand of years. During the beginning of the 20th century camera photography and spectroscopic measurement were often used. Since IGY of 1957-1958 when the present era of space age starts, ballooning, rockets and aircrafts with instruments are gradually adopted, and then the frequent use of polar-orbiting satellites, from early DMSP to recent Polar UV, are duly introduced. At the same time both imaging and measuring equipments are greatly improved, including all-sky TV cameras, HF radar, Imaging Fabry-Perot interferometer and filling photometers.

3 Chronological catalogues and maps of isochasms for auroral visibility.

Dealing with auroras in middle and low latitudes attentions should be paid to archaeo-aurora collections both in Europe and in Far East. The compilation of such a catalogue from a particular country or worldwide is a laudable enterprise, worthy of wide emulation. One of the earliest is that published in 1875 by H. Friz of the Zurich Polytechnic Institute. It covered the period from 503 B. C. to A. D. 1872. Later, F. Link published in 1962 a catalogue of auroras seen in Occident Europe for the period 626 to 1600. Relating to the ancient aurora collections in Japen, Matsushita examined historical data chiefly from Nippon Kisho-Shisgo for the period 176 B. C. to A. D. 1887, classified into 5 groups in reliability and excluded a total of 33 cases of being extremely unlikely, then finally summarized in Table 1 of his article published 1956. In China, Zeng Zhi Quan *et al*. (1982) made a chronology of ancient auroras observed in China, totaling 327 cases with 4 classes of reliability for the period B. C. 2550 to 1911 A. D. Earlier Keimatsu (1965) complied documentary catalogue of northern lights observed in China, Korea and Japan from 7 B. C. to 10 A. D. Recently in cooperation with British Rutherford Appleton Laboratory Yau KKC *et al*. (1995) revised a catalogue of auroral observations from China, Korea and Japan (193BC-AD1770); this catalogue has, as its nucleus, the work of both Keimatsu(1970-1976) and Dai and Chen (1980). All these compilations are valuable; with use of them some preliminary analyses have been made. For example, both Matsushita (1956) and Xu *et al*. (1996) made analysis of the cycles of sunspots and auroras activity respectively in Japan and in China. Also, Keimatsu *et al*. (1968) studied archaeo-aurora and geomagnetic secular variation in historic time; a preliminary examination of the auroral appearance on the same day in the Occident and Orient suggests that the geomagnetic dipole axis might has been inclined towards China around 11-12th centuries A. D. Undoubtly more future works (as listed in § 1 above) could be done with the full use of these data.

From his catalogue Fritz computed, for a number of stations, the average relative frequency of nights with aurora, expressing it M nights per year. Then Fritz drew the first chart for the northern hemisphere, showing lines of equal auroral frequency M; he called these lines isochasms. From this map (here not reproduced) it shows that the lines, beginning with M= 0.1 (one aurora in about ten years), do not follow the circle of geographic latitude; and the frequency of aurora does not increase towards a single polar maximum, but there is an oval or circular zone of maximum frequency. The earth has two auroral ovals, one in each hemisphere; the same statistics and map of isochasms for southern lights (here not reproduced) was made later in 1944 by Vistine and Snyder. Also the ovals are not centered on the dipole poles, their centers appreciably shifted towards the dark hemisphere along the midnight meridian. As the auroral ovals fixed with respect to sun, the earth rotates under it once a day. So the geographic pattern under the oval changes as the earth rotates. Thus, unlike the auroral zone, the auroral oval is not fixed at a particular geographic location at all times. In fact the auroral zone is the locus of the midnight part of the auroral oval on the earth as it rotates once a day. Note also that the character of the aurora varies with local time, in the evening hours well defined arcs and bands are common, usually green in color; after midnight in the early morning hours the aurora is often patchy, and during the daytime hours the auroras are less bright and usually red in color.

4 Analysis of archaeo-auroras in low latitudes during earlier centuries.

We have made a composite list in Table 1, chiefly from 5 major sources, giving notable historic great aurora from AD1101 to AD1938. Here the phrase "great aurora" is similar to "distinct", "unusual" or "outstanding" ones; it is a convenient term to describe combining high visual brightness with progression to exceptionally low latitudes. Of 23 auroras listed, most of them occurred during equinox seasons. Chapman (1957) described 4 great auroras in the table as outstanding tropical ones, as it was seen from Hawaii, Bombay, Singapore and Samoa respectively. Willis and Stepenson (2000) examined the historical auroral records of China, Japan and Korea from ancient times to AD1700. They found that during this period, only 5 examples have been found by 2 or more Oriental auroral observations from separate site on the same night. These occurred during the nights of AD1101 Jan. 31, AD1138 Oct 6, AD1363 July 30, AD1582 Mar. 8 and AD1653 Mar. 2. Thus they are all mid-latitude auroral displays. But there is a good level of agreement from the color of the auroral display (predominary red) and to its position in the sky (usually in northern direction). Recently, Silverman(1995, 2001) made detailed analysis of two great aurora events of 25-26 Sept. 1909 and 14-15 May, 1921, together with some comparison to other three ones occurred in Aug. 28-29 and Sept. 2, 1859 and Feb. 4, 1872. These five cases of visual auroras during past 150 years are very rare, but it is difficult to see how charged particle precipitation producing aurora, normally traveling along magnetic field lines, can reach such low latitude (near equator). Then Silverman collected and discussed all reports and data relating to solar, geomagnetic, auroral and telegraphic distributions. For the 1921 event, the lowest geomagnetic latitude of overhead aurora was 40° and that of poleward horizon 30°. For the two events in 1859, the values were 48°/32° and 41°/26° respectively. By this reason, Silverman was inclined to doubt the Australian newspaper report for Singapore in the 1909 event (from cable disturbance in reality); also he was puzzling for Samoa in 1921 event and proposed other three explanations, i. e. 2000 km high aurora, sunlit aurora and illumination of the upper atmosphere by the invisible aurora, but none convincing.

By the way there are still several points which may be briefly mentioned. (a) Table 2 shows some auroras in Europe during 9th and 10th centuries; all of them are referenced from Link (1962) except two cases with symbol * from Vaquaro & Gallegn (2001). Interesting to note that this most recent paper presents evidence concerning the observation of aurora in the year 880AD and 942AD recorded by Arabs from the Iberian Peninsula and the north of Africa. Keimatsu *et al*. (1968) made also a table (here not reproduced), showing comparison of the number of descriptions of auroras in each century, from 7 B. C. to 10 A. D., in the Occident and the Orient. In total, coincidence of 123 Occidental and 237 Oriental auroras are 34 by year, 7 by month and 2 by day; this may be compared with 7 cases due to Matsushita(1956) and 5 nights due to Willis *et al*. (2000). (b) Referring to Table 1 again for AD 1128 Dec. 13, it is a very particular case to which Willis *et al*. (2001) studied with great interest. From middle of AD 1127 to middle of AD 1129 they analyzed data of solar, geomagnetic and auroral observation, and found about 27-day recurrence existing. There are about 6 times aurora events both in Korea and China, starting at AD 1127 Sept. 20-22, 1127 Oct. 17-20, 1128 Feb. 28, 1128 Oct. 20, 1128 Dec. 13, and ending at AD 1129 Jan. with interval of 27-28 days or its multiple, (c) Lastly, it may be added that Willis *et al*. (1996) found the auroral observation on AD 1770 Sept. 16 being the earliest known conjugate sightings.

5 Aurora observational studies since International Geophysical Year (IGY)

The IGY provided the first opportunity to obtain comprehensive and detailed studies of great auroras. It was a world-wide effort, not only from land, but also from sea and space; auroral observations then made will be simultaneous with observations of other associated phenomena, interplanetary, solar wind and terrestrial. Ways of observation and some advanced instruments have been indicated in part (2) of this paper.

Table 3 shows some recent great auroras since International Geophysical Year; this table is adapted from A. V. Jones (1992 and refs. therein) with some new additions. It is not necessary to describe these auroral cases one by one, here some main items are mentioned. (a) Auroras occurring 1956 Feb. 24-25, 1958 Feb. 10-11 and 1959 Nov. 27 auroras observed in Alaska, where Akasofu *et al*. (1964) started aurora research intensively. Among these three the 1958 event was most interested and investigated. (b) Observation by rocket at Churchill of Canada aimed the aurora by 1970 Aug. 17. (c) Well use of spectrograph measurement mainly due to A. V. Jones (1992) of Canada, referring to 2 auroras observed in Canada. (d) Satellites are used more often, such as DMSP, EXOS-D, ISIS-II, and Polar UV. The aurora 1972 Aug. 4 was observed with ISIS-II. Recently, Zhou and Tsuruteni (1999) discovered and studied shock-aurora events with both WIND interplanetary data and POLAR UV imaging data. (e) Stable Aurora Red (SAR) arcs were better investigated than before, referring to events of 1959 Nov. 27, 1972 Aug. 4 and 1989 Oct. 21 (Oguti 1992) also (Janhunen *et al*. 2000). (f) Some low-latitude auroras: 1957 Sept. 13 and 22, 1969 Mar. 23-24, 1970 Mar. 8, 1981 Apr. 13, 1999 May 13 & 2000 Apr. 7 (STE Lab. of Nagoya University 2000).

6 Concerning prediction of aurora occurrence.

In the past, it is not possible to predict whether tropical auroras will occur; the appearance of a subtropical aurora, however, is not unlikely, though the date or dates cannot be foretold. The uncertainty as to the occurrence of an aurora increases, the lower the geomagnetic latitude. But now to help watch the aurora the World Center will from time to time issue warning notices. The warning notices are of two kinds: 'alert' periods and special world intervals. From the study of archaeo-aurorae in the low latitude (§ 4 of this paper) and extensive auroral observation, since IGY (§ 5 of this paper) we have obtained much knowledge on the relations between polar aurora and low-latitude aurora, also between geomagnetic disturbance and great aurora display. For example, during intense geomagnetic storms, the auroral oval both expands and moves equatorward, occasionally becoming visible from tropical latitude. Again, the recurrence of aurora display nearly conjoins the recurrence of geomagnetic activities. Thus, ways of predicting geomagnetic disturbance may be similar with, or led to ways of aurora prediction. For this purpose two papers of us might be referenced (Tschu and Zhang 1984; Zhou and Tschu 1994). In brief, methods of prediction are of different kinds applied to measured quantities or derived indices; they are experiential estimation, correlation statistic analysis, physical models, system control, artificial intelligence and synthitic prediction such as Neural Networks-Expert System. Of course, along with understanding in-depth of the problem involved, further efforts in research should be needed in future time.

Table 1. List of notable historical great auroras from AD 1011 to A. D 1938

Date, AD	Where seen	Ref.	Date, AD	Where seen	Ref.
1101 Jan. 31	China, Korea,	B	1788 Oct. 22	Spain, Rome,	E
	Japan			N America, Japan	
1128 Dec. 13	Korea, China	B	1839 Sept. 15	London	A
	(27 day recurrence)		1843 Mar. 2-13	Higher & Central	E
1138 Oct. 6	China, Korea, Japan	B		Japan	
1363 July 30	China, Korea, Japan	B	1859 Aug. 28-29	N America	A, C
1582 Mar. 8	China, Korea, Japan	B		Jamaica, Rome	
1591 Oct. 5	Nuremberg	A	1859 Sept. 2	America, S. Salvador	A, C, E
1653 Mar. 2	China, Korea, Japan	B		Athens, Philadelphia,	
1681 Feb. 10	Pressberg, Hungary	A		Japan, Hawaii	
1716 Mar. 17	Europe	A	1872 Feb. 4	Mexico, Athens(Zenith)	A, C, E
1730 Feb. 15	Rome, Austria,	E		Philadelphia, Japan,	
	Paris, Sweden,			Bombay	
	Central Japan		1909 Sept. 25-26	Singapore(12°S)	A, C,
1770 Sept. 16	Paris, Vienna,	B, E		Bataria, Hokkaidd	D, E
	China, Central		1920 Mar. 22-23	Oslo, Washington	A
	& N. Japan		1921May 14-15	Samoa(13°S)	A, C, D
1786 Mar. 1	Petersberg,	E		Jamaica	
	Central Japan		1926 Jan 26	Scandinavia	A
			1938 Jan. 25-26	Oslo, Azores	A
				N. Africa	

Notes: Ref. A see Jones, 1992; B see Willis *et al*. 1996, 2000, 2001; C see Chapman 1957; D see Silverman *et al*. 1995, 2001; E see Matsushita 1956.

Table 2. List of some auroras in Europe during 9th and 10th Centuries.

Date AD	Where seen	Date AD	Where seen	Date AD	Where seen
861 Mar. 10	France	934 Oct. 14	France	945 Sept. 15	Germany
870 three times	Gernany	937 Feb. 14	France	945 Oct. 25	England
880* Jan. 25	Iberian	940 Dec.	France	955 Jun.	France
888 Jan. 13	Sea	941	Swiss		
890 Jan. 1	England	942* Apr. 27	N. Africa		

All from Link (1962), except two cases marked * from Vagnrro and Galleqn (2001).

Table 3. Some more recent great Auroras*

Date AD	Where seen	Ap	Date AD	Where seen	Ap
1956 Feb. 24-25	Alaska	103	1971 Dec. 17-18		67-22
1957 Sept. 13	Mexico	160	1972 Aug. 4	ISIS-II, SAR arc	132
1957 Sept. 22	Mexico	104-164	1977 Dec. 1-2	Morning-dayside,	6-69
1958 Feb. 10-11	N. America	24-199		type A red	
	Mexico, USSR		1981 Mar. 5	Thermal, Boulder	81
1958 Sept. 3-4	Canada	64		(type A)	
1958 Sept. 4-5	Canada	131	1981 Apr. 13	Arizona	181
1959 Nov. 27	Red arc from	15-82	1982 July 13-14	Major storm	144-157
	Alaska to New Mexico		1989 Mar. 13		246
1969 Mar. 23-24	Low Latitude	47-79	1989 Oct. 21	EXOS-D, Japan	
1970 Mar. 8	Low Latitude	149	1999 May 13	weak SAR arc, Japan	
1970 Aug. 17	Rocket Observations	115	2000 Apr. 7	Strong SAR arc, Japan	
			2003 Oct. 30	Alaska, Germany, Madrid	

* Adapted from Jones AV (1992 and refs there in) with some new additions. Ap is geomagnetic index.

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