天文辐射量的变化与气候变迁

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关键词　气候变迁　天文辐射量的变化　冰期的成因

内 容 提 要

关于过去30万年内的全球各纬度地区的天文辐射冬、夏半年总量的变化已可精确地计算得到(图1b—1c)。深海的沉积物又提供了关于这一时期的最完整、最精确的气候变迁的资料(图1a)。将两者进行对比可知：1.温暖期和寒冷期在图1b—1c上的表现是截然不同的。这种差异突出地表现在低纬度地区，而不是表现在高纬度地区。2.温暖期的气候波动比寒冷期更为剧烈。3.寒冷期的气候不应当与天文辐射量的增多(图1c)相对应；而只能与天文辐射量的减少(图1b)相对应。

在最近的十多年内，人们对更新世的气候变迁的情况已有了较多的认识，因为深海沉积物为我们提供了不少连续的、完整的氧同位素记录。在中、晚更新世(即在最近的73万年内)共发生了8次完整的冰川旋回(B-I)。每个旋回的前半部分被称为温暖期(相当于第5、7、9、11、13、15、17、19等阶段)，而后半部分则为寒冷期(第2—4，6，8，10，12，14，16，18等阶段)。对于陆上沉积物的研究也得到同样的结果。

不少学者对深海沉积物所提供的氧同位素记录进行了频谱分析，他们发现：构成气候波动的几种最主要的频率带恰好与地球轨道三要素的变化周期相一致。所以不少科学工作者接受了如下观点：地球轨道的变化是引起更新世气候变迁的根本原因。可是到目前为止，人们还不知道地球轨道的变化究竟是怎样控制气候变迁的。米兰柯维奇把注意力集中在北纬65°地区天文辐射夏半年总量的变化上(即米氏曲线)。他认为该曲线的升降与全球性冰川的消长相一致。事实证明：米氏曲线与氧同位素记录并不吻合；而北纬35°地区天文辐射冬半年总量的变化与氧同位素记录颇为一致(徐钦琦，1980)。

Berger (1978) 用图表分别地展示了过去100万年内全球各纬度地区的天文辐射冬、夏半年总量的变化(图1b—1c是过去30万年内的变化情况)。将它与深海沉积物所提供的氧同位素记录作对比，可得到如下认识：

1.温暖期与寒冷期的交替出现是更新世气候变迁的最重要的特征之一。由图1a可知：第1、5、7、9等阶段代表温暖期，而第2—4、6、8等阶段代表寒冷期。换言之，第2—5、6—7、8—9等阶段分别组成三个冰川旋回。据Hays等(1976)研究，第5、6阶段的界线距今约127,000年，而第7、8阶段的界线距今约247,000或251,000年。由此，第1—9阶段便可在图1b—1c上得到它们相应的位置。根据图1a与图1b—1c的对比，在温暖期(即第5或7等阶段)，天文辐射量的变化显得十分剧烈，等值线的排列非常紧密；而在寒

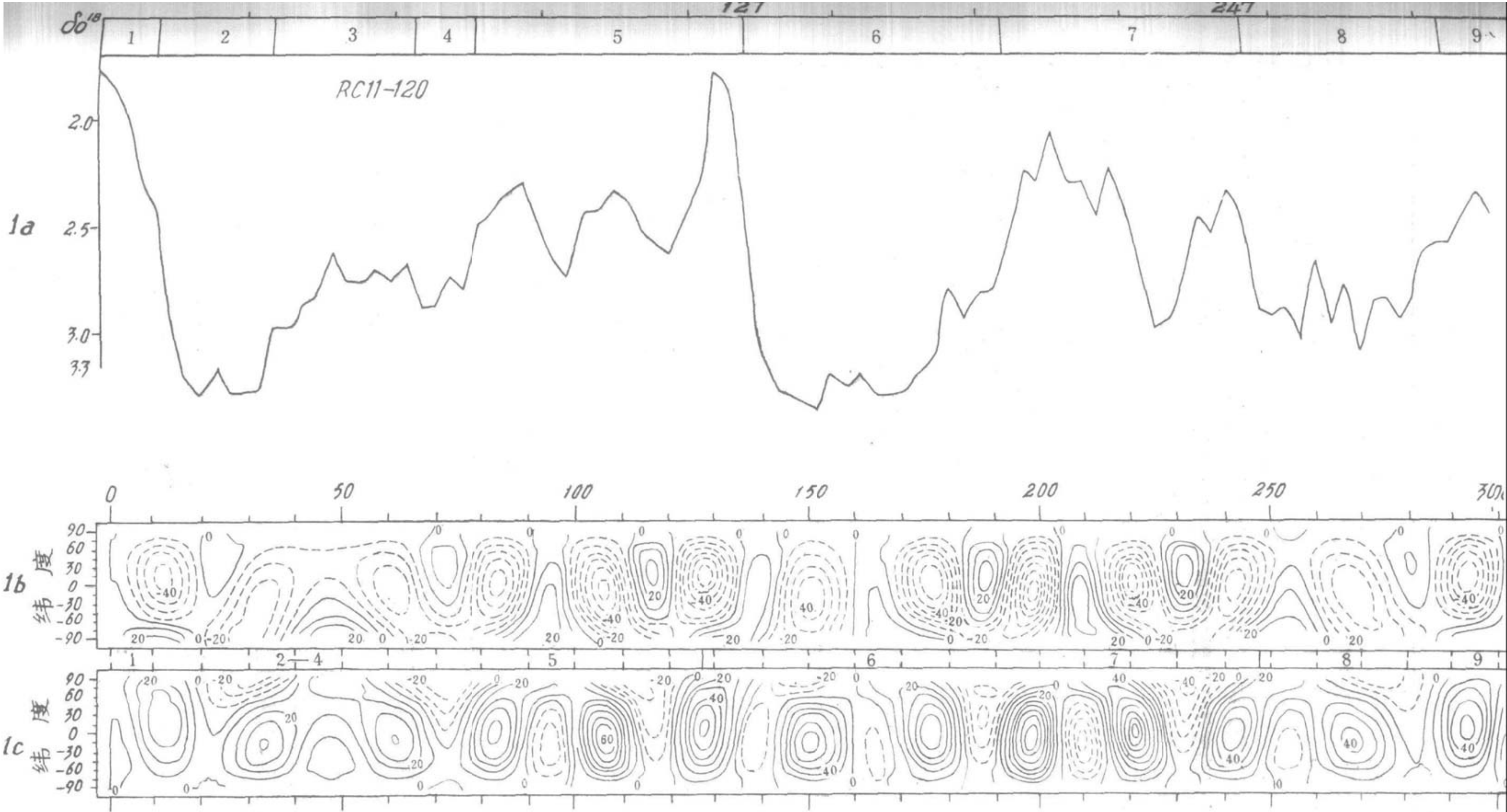

图 1a：由 RC11—120 深海钻孔所提供的氧同位素记录。其中第 1、5、7、9 等阶段代表温暖期；而第 2—4、6、8 等阶段则代表寒冷期。

图 1b—1c：在过去 30 万年内，全球各纬度地区天文辐射冬、夏半年总量的变化(以 1950 年的值为零点)。b：北半球冬半年，南半球夏半年天文辐射总量的变化；c：北半球夏半年，南半球冬半年天文辐射总量的变化。

Fig. 1a: Oxygen isotope record in core RC11—120. The stages 1, 5, 7, 9 correlate with the warm stages; while the stages 2—4, 6, 8 with the cold stages. (after Hays, *et al.*, 1976) Fig. 1b—c: Deviations of solar radiation (langleys/day) from their 1950 A. D. values; b: Caloric winter northern hemisphere and caloric summer southern hemisphere; c: Caloric summer northern hemisphere and caloric winter southern hemisphere. (after Berger, 1978). According to Hays *et al.* (1976), the age of isotopic stage 8-7 boundary is at about 247,000 or 251,000 years, and the age of stage 6-5 boundary is at about 127,000 years. Thus the stages 1—9 get their possible positions in Fig. 1b—c.

冷期(即第2—4、6、8等阶段),天文辐射量的变化显得相当微弱,等值线的排列也颇为稀疏。所以,无论在北半球,还在南半球,无论在冬半年,还在夏半年,天文辐射量的变化在温暖期和寒冷期的表现是截然不同的。两者的差异主要不是表现在高纬度地区,而是表现在低纬度地区,如图1b—1c所示。因此我们认为,对全球性气候变迁起决定性作用的似乎不是米氏所强调的北纬65°地区,或其它高纬度地区,而是以赤道为中心的低纬度地区。这不仅是因为低纬度地区的天文辐射量的变化幅度明显地超过高纬度地区(如图1b—1c所示),而且还因为地球表面是近似的球面,因此高纬度地区实际上只占全球总面积中极小的一部分(介于北纬30°与南纬30°之间的低纬度地区占全球总面积的50%;介于北纬45°与南纬45°之间的地方约占全球总面积的71%;而介于北纬60°与南纬60°之间的地方则占全球总面积的86.6%;故纬度超过60°的高纬度地区仅占全球总面积的13.4%)。总之,温暖期与寒冷期在图1b—1c上的表现是截然不同的。

2. 在代表温暖期的第5、7等阶段,天文辐射量的变化十分剧烈(如图1b—1c所示),所以温暖期的气候不仅应当有波动,而且这种波动还应相当剧烈。事实恰好证实了这一点。在深海钻孔的氧同位素记录中,Shackleton (1969) 把第5阶段分成五个亚阶段,按年龄新老顺序标以5a—5e。其中5a、5c、5e的O^{18}/O^{16}比值低,反映气候温暖;而5b、5d则相反,反映气候寒冷;5e是五个亚阶段中氧同位素比值最小的,反映气候最暖。同样 Ninkovitch and Shackleton (1975) 又把第7阶段分成亚阶段7a、7b和7c。根据 Aharon, Chappell and Compston (1980) 的研究,在第5阶段共出现了三次高海面,它们可以分别与第5阶段的三次暖峰(5a、5c、5e)相对应。在中国北方的黄土地区,如在陕西洛川的剖面中,第12层是全部古土壤条带中最突出的。它包括三条密集的古土壤,被称为第一个"红三条"。它不仅颜色鲜艳,厚度也较大,达5.67米。它发育着完好的土壤发生剖面,有十分明显的粘化层和碳酸盐淀积层,钙质结核个体也最大。用热发光法测定第12层古土壤的年龄为距今178,000—212,000年,所以它相当于氧同位素记录的第7阶段。在现代,象这样色彩鲜艳的红色的土壤只是在中国的南方才能够形成。所以,在第12层"红三条"的形成期间(即第7阶段)曾出现过三次十分温暖湿润的气候环境,那时的陕西洛川的气候与今日华南的气候相类似。在上述代表三次暖峰的"红三条"之间,均有黄土堆积。这些黄土与上复或下伏地层中的黄土没有实质性的区别。据刘东生等研究,黄土乃是寒冷期的产物。由此可见,第7阶段共包括三个温暖的亚阶段(其温暖的程度超过邻近的其它的温暖期),以及两个寒冷的亚阶段(其寒冷的程度与其它寒冷期相接近)。因此,第7阶段乃是气候波动尤为剧烈的时期。第5阶段也是类似的。总之,第7、5等阶段的气候的剧烈的波动与当时天文辐射量的十分剧烈的变化有关。

3. 在寒冷期(即第2—4,6,8等阶段),无论在图1b或图1c上,其天文辐射量的变化都不很剧烈。但是,这种辐射量的变化在两个图上的表现却是截然不同的。例如,在第2—4阶段(即末次冰期,它在中国被称为大理冰期),在世界上的绝大部分地区内,其天文辐射量在图1c上均表现为正异常。换句话说,在末次冰期,在北半球的夏半年或南半球的冬半年,世界上绝大部分地区所获得的天文辐射量都比现代(以1950年为代表)更多。然而,无数的古气候证据表明:世界各地在末次冰期时,年平均温度皆比现代更低。米氏认为,北半球天文辐射夏半年总量的多寡(图1c)会对全球性气候变迁起决定性的作用。

显然，末次冰期的寒冷气候是不应当与天文辐射量的增多相对应的。我们认为，它应当与天文辐射量的减少相对应。事实上，在末次冰期，在北半球冬半年或南半球夏半年，世界上绝大部分地区所获得的天文辐射量都比 1950 年的值更少(图 1 b)。所以，对全球性气候变迁起决定性作用的，不是米氏所强调的北半球夏半年，而是北半球冬半年的天文辐射量的变化。

根据现代气候学家的研究，北纬 35° 地区所获得的太阳辐射量（短波）与地球释放出的长波辐射量恰好相近。所以我们认为：北纬 35° 地区天文辐射冬半年总量的多寡大体上可代表全球平均气温的升降。过去 30 万年内气候变迁的历史恰好说明了这个论点。

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CLIMATIC VARIATIONS AND DEVIATIONS OF SOLAR RADIATION IN THE PAST 300,000 YEARS

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Key words Climatic variations Deviations of solar radiations Astronomical theory of ice ages

Summary

The ratio of oxygen isotopes O^{18} to O^{16} in foraminiferal tests provides a complete record of global climatic changes. The record shows 19 stages in the Brunhes normal epoch of about 730,000 years. The odd numbered stages correlate with warm intervals, while the even numbered ones with cold intervals. In loess areas warm-cold cycles were recorded by repeated alternations of forest soils and loess. The correlation of European loess with the deep-sea sediments has been made by Kukla. Dated flights of raised coral reef terraces indicate that high sea levels coincide with warm stages, while low sea levels with cold stages.

It is now clear that a significant part of the observed climatic variations over the past 730,000 years is concentrated in narrow frequency bands near cycles of 23,000, 42,000, and approximately 100,000 years. These peaks correspond to the dominant periods of the earth's solar orbit, because the average period of the variations in eccentricity is about 90,000 years; that of the obliquity of the ecliptic 41,000 years; and that of the longitude of perihelion 21,000 years. Therefore many scientists hold that changes in the earth's orbital geometry are the fundamental cause of the succession of Quaternary ice ages. Milankovitch focused attention on a curve representing variations in radiation received during the summer half-year at 65°N. This particular version of the astronomical theory is often referred to as the Milankovitch theory of the ice ages. However, Milankovitch curve shows its poor correlation with the paleoclimatic record. As a matter of fact, the curve of distribution of winter halfyear radiation at 35°N coincides almost exactly with the paleotemperature curve (Xu Qinqi, 1980). It is probable that the distribution of winter half-year radiation at 35°N would be critical to the variation of the mean annual temperature of the world.

Changes of radiation can be calculated with great precision for the past million years (Berger, 1978). It is possible to test the astronomical theory of the Pleistocene ice ages by comparing the record of Pleistocene climate (Fig. 1a) with the deviations of solar radiation of the whole world in both winter and summer half-year during the past 300,000 years (Fig. 1b—1c). According to Hays *et al.* (1976) the age of isotopic stage 8—7 boundary is at about 247,000 or 251,000 years, and the age of stage 6—5 boundary is at about 127,000 years. The possible positions for stages 1—9 are shown in Fig. 1b—1c. The comparison of the record of Pleistocene climate (Fig. 1a) with the deviations of solar radiation (Fig. 1b—1c) shows three characteristics.

1. The swings of radiation levels are quite large and the radiation levels pack closely ring upon ring during the warm stages (i.e. stages 5 and 7), while the swings are small and the arrangement of the radiation levels is scattered during the cold stages (i.e. stages 2—4, 6, 8). The most obvious differences between warm and cold stages are at low latitudes, rather than at high latitudes.

The belt between 30°N and 30°S covers 50 per cent of the earth surface, the belt between 45°N and 45°S covers about 71 per cent, and the belt between 60°N and 60°S covers about 87 per cent. It seems that the deviations of solar radiation at low latitudes, rather than at high latitudes, are the fundamental cause of the climatic variations.

2. Climate would fluctuate wildly during the warm stages due to the quite large swings of radiation levels (Fig. 1b—1c). As a matter of fact, stage 5 was further subdivided by Shackleton (1969) into substages labeled 5a to 5e in order of increasing age. Substage 5e has the lowest isotopic ratio of the five. It corresponds to the minimum volume of ice and is considered to represent the last interglacial. Similarly, stage 7 was subdivided into 7a, 7b, and 7c. Sea level records shown by Aharon, Chappell and Compston (1980) support this. Dated flights of raised coral reef terraces indicate that high levels in the last 200,000 years coincide with warm peaks of the isotopic record. In the loess area of northern China, there is good evidence too. For example, in the Luochuan loess section in Shaanxi Province. Layer 12 is the most outstanding forest soil of all the soils of the Luochuan sequence. It is composed of three compact red beds denominated the "Three Red Bands". By TL dating, the date of Layer 12 is 180,000—210,000 years. So Layer 12 corresponds to stage 7. The red soil is restricted to southern China today. Therefore the red beds of soil indicate that the climate at Luochuan was as warm as in southern China at that time. Layer 12 must have been deposited at the warmest stage when there were three successive outstanding warm peaks. However, between these red soils, there is also loess which appears similar to the loess in overlying and underlying strata. Just as Kukla (1977) said, in the loess area glacial-interglacial cycles are represented by repeated alternations of loess and forest soils. The existence of the loess in Layer 12 indicates that the climate at Luochuan was as cold as the cold stages when the loess was depositing. As mentioned above, Layer 12 is correlated with stage 7. Therefore the climatic fluctuations were more extreme during stage 7. It may have been the same during stage 5. It seems to us that the quite large swings of radiation levels coincide with the extreme climatic fluctuations of stages 7 and 5.

3. During the cold stages (i.e. stages 2—4, 6, 8), the swings of radiation levels are small in both Fig. 1b and Fig. 1c. However, the deviations of solar radiation from their 1950 A. D. values are positive in the most part of the world in Fig. 1c; while those are negative in Fig. 1b. Therefore in the cold stages, the deviations of caloric summer northern hemisphere and caloric winter southern hemisphere are positive; while those of caloric winter northern himisphere and caloric summer southern hemisphere are negative (Fig. 1b—1c). It is impossible that the cold climate corresponds to the positive deviations in Fig. 1c as Milankovitch thought (i.e. during the summer half-year at 65°N). Obviously, the cold climate corresponds only with the negative deviations in Fig. 1b. Therefore the deviations of caloric winter northern hemisphere and caloric summer southern hemisphere coincided with the climatic variations in the

past 300,000 years.

On the basis of the climatologists' work, the incoming solar radiation is equal to the outgoing earth radiation at 35°N. So I am convinced that the distribution of winter half-year radiation at 35°N would be critical to the variation of the mean annual temperature of the world.