Proc. Indian Acad. Sci. (Earth Planet. Sci.), Vol. 102, No. 1, March 1993, pp. 241–247.

Evolution of India's monsoon climate through geological times

KSHUDIRAM SAHA
27, B-Road, Maharani Bagh, New Delhi 110065, India

Abstract. Using the theory of plate tectonics and a concept of climate analogs, the paper speculates that a monsoon type of climate with warm and wet summer and cold and dry winter might have first appeared over the northern part of India when during its northward drift across the Tethys Ocean (now the Indian Ocean) it was located over the subtropical belt of the southern hemisphere some 60 million years before present (BP). The monsoon climate gradually evolved and extended to other parts of India as the Indian plate after crossing the equator about 50 million years BP moved further northward and collided against the north Asian plate giving rise to the Himalayas along the northern boundary of India some 40 million years BP. Recent studies suggest that despite short and long period fluctuations, no major secular change or trend has taken place in the monsoon climate of India since then.

Keywords. Climate history; tectonic movements.

1. Introduction

A monsoon type of climate with warm and wet summer and cold and dry winter has prevailed over India for millions of years. A similar type of climate has also existed over some other parts of the global tropics, such as central parts of Africa and America, southeast Asia, northern Australia and even over open oceans. It is well-known that this type of climate is characteristic of regions where the sun during its seasonal movement across the equator produces differential heating between adjacent latitudinal belts of the earth's surface, whether that surface is land or water. Monsoon develops strongly when the region has land-sea thermal contrasts mainly due to difference in specific heat between land and water. In the Indian monsoon region, the presence of the Himalayas adds a new dimension to the strength of the monsoon by extending the rainfall regime to the northern parts of the country during summer and by protecting India from the icy cold winds of central Asia during winter. In other words, what makes the Indian monsoon the most powerful among the monsoons of the world would appear to be a combination of three important geophysical factors. These are:

- A favourable geographical location at the southern periphery of the Asian continent with the Tropic of Cancer passing through it and the vast Indian Ocean lying to its south;
- Strong land-sea thermal contrast, especially during summer; and
- The presence of the Himalayan mountain barrier along its northern boundary.

2. Early history

Geologists tell us that the above features related to the Indian monsoon climate did not exist in the geologic past, say a billion years before present (BP). In fact, there is very little authentic information available about the past climates of the earth. Whatever little seems to be known today has been based on indirect evidence drawn from painstaking examinations of fossil records, different kinds of rocks, deep-sea sediments, biological processes in plants and animals, tree-rings, etc. and the rest is mostly speculative. However, there appears to be unanimity among scientists that when our earth was born nearly 4·6 billions years BP, it had no atmosphere of the type as we know it today. Neither did it have a solid crust on which the continents formed, with the oceans around them. These features appeared much later in geological history, as the earth, once a part of the glowing hot sun, started cooling and de-gassing and other geophysical and geochemical processes continued. The formation of an atmospheric environment was, perhaps, complete even before the end of the pre-Cambrian era more than 4 billion years BP and not much change has occurred since then. But the different layers of the earth's crust and interior were still in turmoil and in the process of relative gravitational adjustment. The theory of plate tectonics tells us that even in early Carboniferous period about 300 million years BP the only two great land masses that occupied the earth's surface were Laurasia in the north (near about the present North Pole) and Gondwanaland in the south (near about the present South Pole). Laurasia consisted of the present North America, Europe and northern Asia (north of the present Himalayas), while Gondwanaland was a conglomerate of several land masses or continents which could be identified with present-day India (without the Himalayas), South America, Africa, and Australia. In the late Carboniferous period about 200 million years BP, Gondwanaland broke up and the constituent land masses started drifting away from each other. The Indian land mass moved approximately northward and occupied a position across the equator about 50 million years BP. In course of time, it moved further northward and collided with the land mass of northern Asia which was carried on a different plate. On collision, the Indian plate slided beneath the Asian plate thereby producing a subduction zone between the two plates which gave rise to the present Himalaya mountains along the northern boundary of India. This collision might have taken place during the late Cainozoic period about 40 million years BP. A vigorous monsoon developed over India after this collision event. But the question that is of paramount interest here is what sort of climate prevailed over India prior to its reaching the present geographical location. There cannot be any question of its having had a monsoon type of climate while it moved over the southern high latitudes, since monsoon is basically a tropical phenomenon. It is likely that a monsoon type of climate first appeared on it when it entered the subtropical belt of the southern hemisphere. This question is examined in the remaining pages of this paper.

3. Past climates

The theory of plate tectonics which has been immensely successful in explaining many geological and geophysical phenomena relating to the earth comes to our aid in tackling this question, though in an indirect way. It says nothing about the climate

but from it we may deduce where India possibly had been at different stages of its drift across the Tethys Ocean, if it is assumed that India moved northward without any change of size or shape at a more or less uniform speed. Since it lay across the equator about 50 million years BP and the Tropic of Cancer about 40 million years BP, it works out that India had reached the Tropic of Capricorn about 60 million years BP. What was India's climate then and how did it evolve? Obviously, a direct answer to these questions is not possible in the absence of any atmospheric data or other geophysical or geochemical evidence relating to that period. Any attempt that may be made in this direction has, of necessity, to be indirect. However, if it is assumed that some of the background parameters of the earth's climate system, such as the Solar constant, the earth's orbital motion around the sun, the seasonal oscillation of the sun about the equator, the physical properties of land and sea, atmospheric composition, etc., which control climate, have not changed materially during geological times under consideration, then there appears to be some hope of our hinting at the past climates of India making use of what may be termed as the theory of climate analogues. The idea here is to look for a land mass of comparable size which is currently located in the same latitudinal belt as India had been in a given geological period and whose present climate is accurately known from recorded data.

Taking this approach, we consider at least three stages in the evolution of India's past climates, the first about 60 million years BP when India was in the southern hemisphere, the second about 50 million years BP when it lay across the equator and the third when it reached its present geographical location. The third stage can again be divided into two substages, before and after the rise of the Himalayas. Here we would like to emphasize the limitations of this approach, since the analogues we choose may not be the ideal ones. Nevertheless, having known climatic conditions in selected analogues, we feel encouraged to speculate at least qualitatively on several aspects of the past climate of India, such as pressure patterns, prevailing wind systems, temperature, rainfall distribution, etc.

4. Climate 60 million years BP

A close analogue of India's climate 60 million years BP appears to be that of present-day Australia, though the two land masses differ in size (India's 3·2 as against Australia's 7·6 million sq.km) and shape (India's rather oblong as against Australia's rather rectangular). Here, analogy is judged more by geographical locations and land-sea thermal contrasts than by any other parameter. As stated in section 2, both India and Australia formed part of Gondwanaland at the beginning of the continental drift. Evidently they moved in different directions and at different speeds to arrive at their present geographical locations. Situated between latitudes about 10 S and 44 S and longitudes 113 E and 153 E, present-day Australia has a monsoon type of climate the essential features of which during January and July are broadly known from recorded data. Modelled after this climate, India's climate 60 million years BP might possibly have been as presented in table 1 and schematically shown in figure 1.

Figure 1 is self-explanatory but we would like to point out that a monsoon type of climate, perhaps, appeared for the first time over India when its northern territory started having warm and wet summer (southern summer) and cool and dry winter (southern winter) when geographically it lay across the Tropic of Capricorn (23·5 S) some 60 million years BP.

Table 1. Possible climatic elements over India 60 million years BP.

Element	January	July
Pressure pattern	Low over northern territory, high to the south	High over whole sub-continent, low to north of equator
Prevailing wind system	Northwesterly/westerly in north, easterly in south	E/ESEasterly in north, westerly in south
Temperature	Generally warm	Generally cool
Rainfall	Rainy in north (north of pressure trough), mainly dry in south	Mainly dry over most of India but some rain in extreme south.

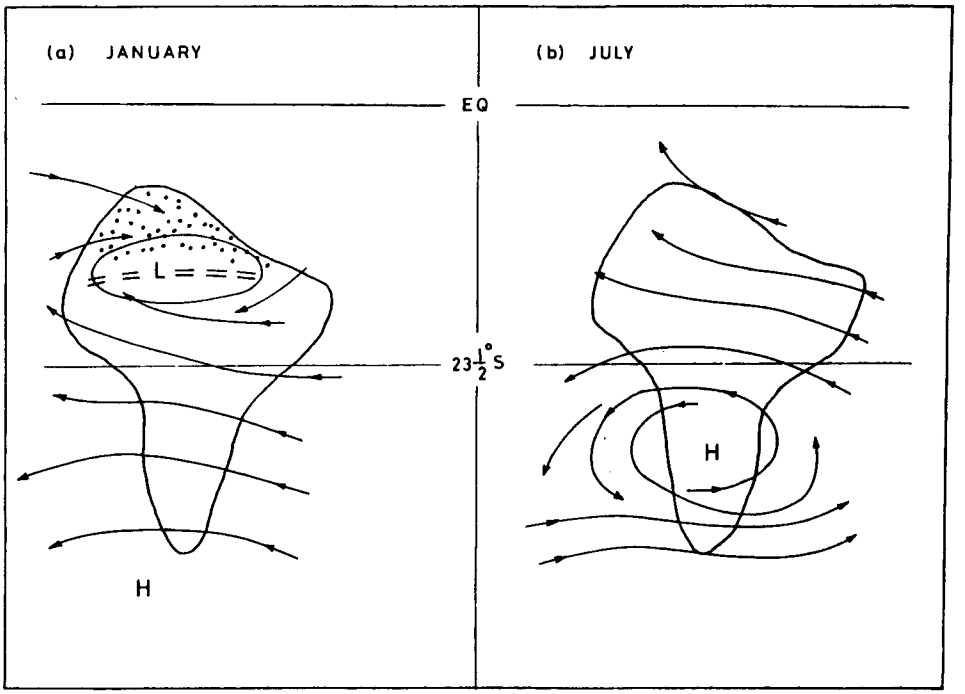

Figure 1. Schematic showing possible climatic conditions over India when it was located in the southern hemisphere: (a) January, (b) July. L denotes Low and H High pressure; Double-dashed line indicates trough of low pressure; Arrow-lines show directions of prevailing winds; Rainfall areas are stippled.

5. Climate 50 million years BP

India lying across the equator about 50 million years BP might have looked like a mini version of present-day Africa which extends in latitude from about 35 S to about 35 N or South America covering a latitude belt from about 55 S to about 12 N, both of which are known to have a monsoon type of climate over their equatorial regions, though there is considerable latitudinal shift of the rain-belt between January and July. Modelled after the present-day climate of either of these continents, India's

Table 2. India's climatic elements 50 million years BP.

Climate element	January	July
Pressure pattern	Low over southern and high over northern India	Low over northern and high over southern India
Prevailing wind systems	Northeast trades over northern India N/NW winds to north and southeast trades to south of trough of low over southern India	Easterly to north and W/SWesterly to south of the trough of low pressure. Generally SE trades south of equator
Temperature	Generally cool over northern and warm over southern India	Generally hot over northern and warm over southern India
Rainfall	Rainy over equatorial belt between about 5 N and 15 S, mainly dry elsewhere	Rainy over equatorial belt between about 15 N and 5 S. Mainly dry elsewhere.

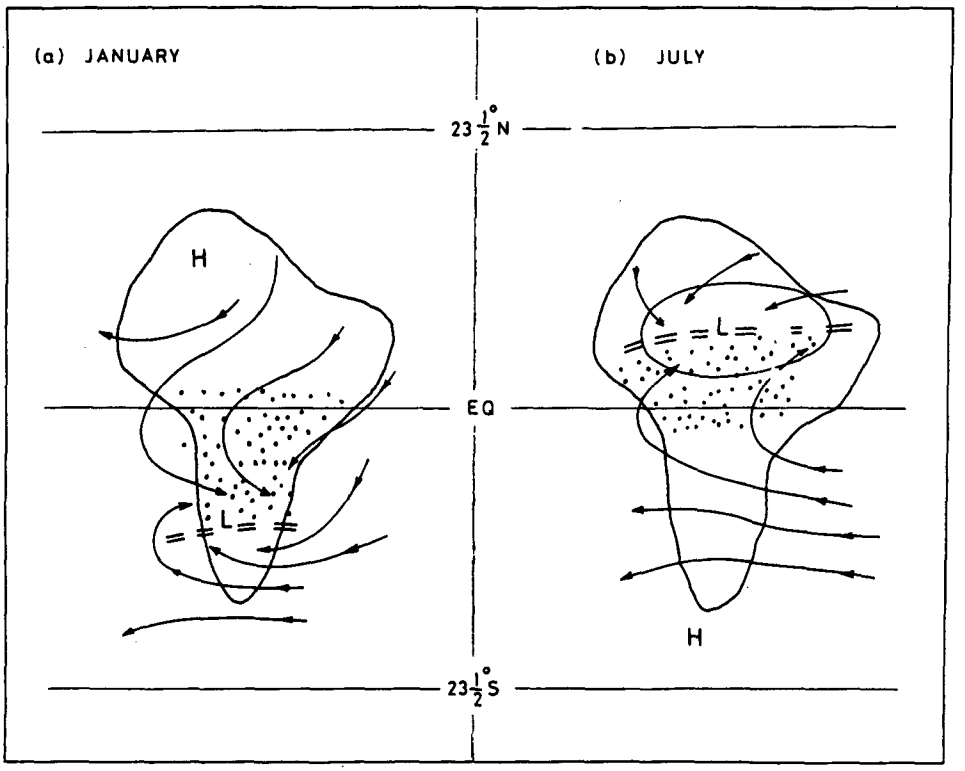

Figure 2. Same as in figure 1 but with India located at the equator some 50 million years BP.

possible climate some 50 million years BP when it lay across the equator might have had the features described in table 2 and schematically shown in figure 2.

One may note from figure 2, when compared to figure 1, a distinct change in climatic conditions especially in the distribution of rainy areas that occurred between 60 and 50 million years BP. When India was located south of the equator, the major rainbelt was to the north of the trough of heat low but when it lay across the equator the major rainbelt shifted to the equatorial belt to the south of the trough of low

pressure in the northern hemisphere during July. This change was maintained as India continued to move further into the northern hemisphere to its current geographical location between about 8 N and 32 N about 40 million years BP.

6. Climate 40 million years BP

What was the climate of India like when it reached its present geographical location? As already mentioned in earlier sections, a monsoon type of climate had already appeared, starting first over northern India when India was in the southern hemisphere and then shifting to central and southern parts while it lay across the equator. The evolution continued and new and wider areas of India came to be covered by it as the Indian plate continued to move further into the northern hemisphere colliding against the north Asian mainland plate giving rise to the Himalayas. So we have here two distinct climatic situations, one before and the other after the rise of the Himalayas, as depicted in figures 3 and 4, respectively.

Before the rise of the Himalayas, monsoon was mainly confined between the summer and the winter locations of the trough of surface low pressure. Further, the orientation of the troughline was more latitudinal than it is today. This means that most of northern India which lay to the north of the summer heat low trough had a hot and dry climate and this area included most of present-day states of Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, Bihar, North Bengal and Assam.

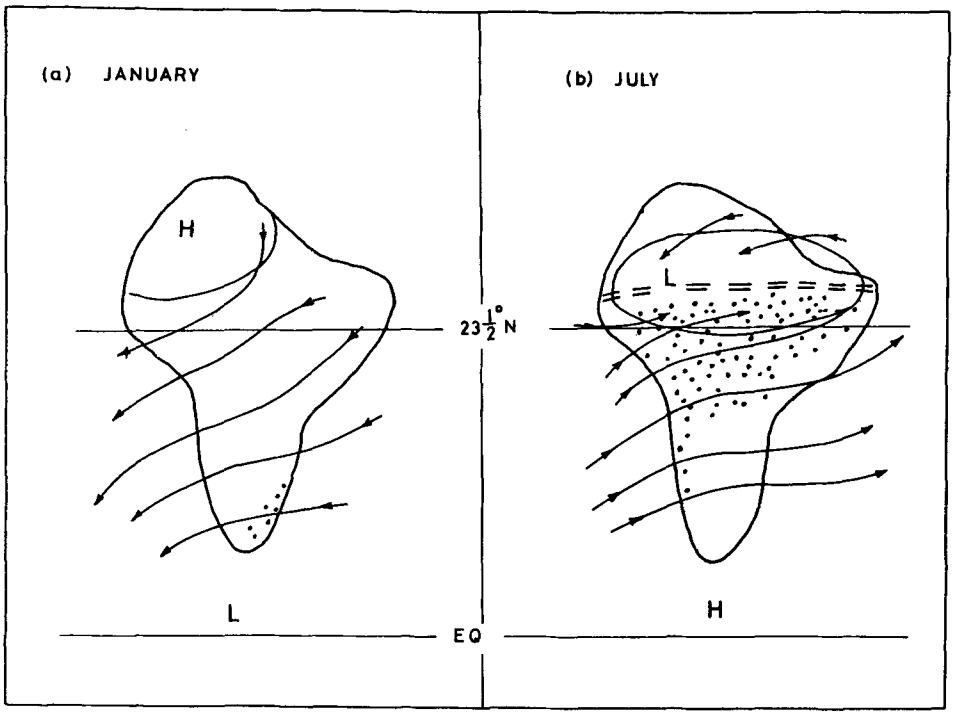

Figure 3. Same as in figure 1 but with India at its present location before rise of the Himalayas about 40 million years BP.

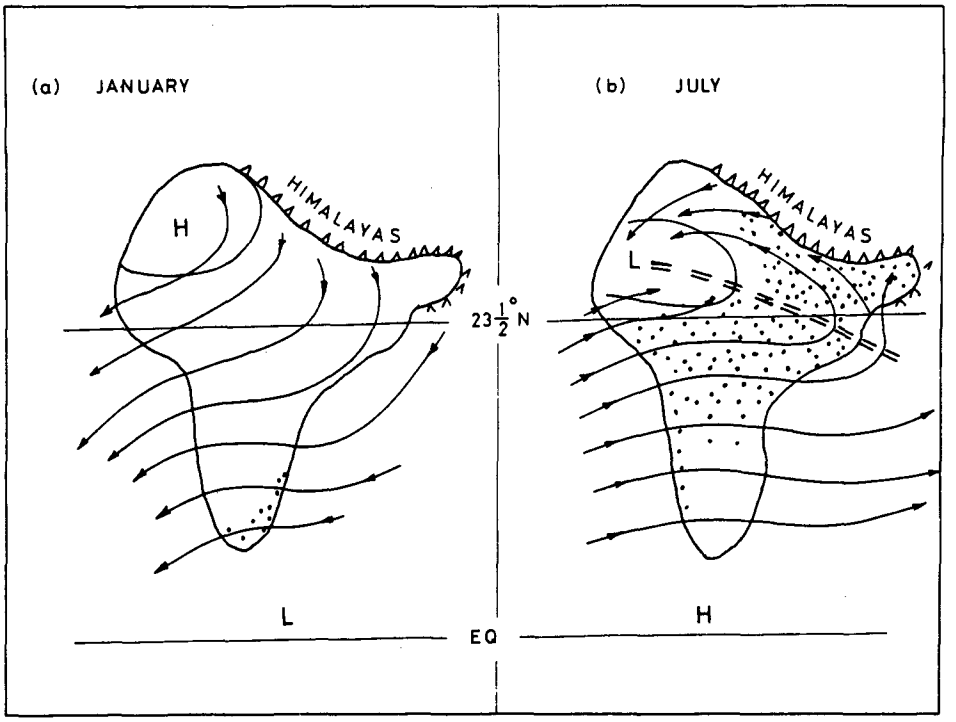

Figure 4. Same as in figure 3 but after the rise of the Himalayas.

The rise of the Himalayas, therefore, meant a great deal for the climate of northern India. Moisture-laden summer monsoon winds were now stopped by the mountains and copious rain fell along the mountain belt, extending the rainbelt well to the north of the trough of low pressure. During winter, the high mountain ranges protected northern India from the icy cold winds of central Asia. In short, it is difficult to overestimate the importance of the Himalaya mountains in shaping the monsoon climate of India and contributing to the granary of northern India. One may even say that without the Himalayas, northern India would have been a barren land like Rajasthan or the desert belt of Iran, Iraq or Saudi Arabia of Asia or the Sahara desert of north Africa.

In the foregoing, we have made the tacit assumption that the monsoon climate of India has not changed materially since the Himalaya mountains came into being and India's further northward movement practically came to a halt. This assumption may not be quite true. Recent studies based on recorded observations of the atmosphere do bring out fluctuations of climatic conditions over different time and space scales but no long-term or secular change has been in evidence over India (Mooley and Shukla 1987).

Reference

Mooley D A and Shukla J 1987 Variability and forecasting of the summer monsoon rainfall over India; *Monsoon Meteorology* (eds) Chang and Krishnamurti (New York: Oxford University Press) pp. 26–59