Local Meridional Circulation and Deserts①

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ABSTRACT

This paper investigates the dry climatology of Sahara and Northwest China deserts from the viewpoint of local meridional circulation with Xie and Arkin rainfall dada and NCAR / NCEP reanalysis data. Results show that there are very dry centers with annual rainfall less than 50 mm over these two deserts while the rainy seasons are very different. In the south part of Sahara desert center and Northwest China desert, over 70% rainfall takes place in June, July and August (JJA). While in the north part of Sahara, rainfall mainly concentrates in December, January and February (DJF). The local biosphere–radiation mechanism proposed by Charney cannot explain the climatology of such very dry centers. Neither can the monsoon–desert mechanism proposed by Rodwell and Hoskins do for the strongest descent center is much more northward than the driest center over Sahara in JJA. From the viewpoint of local meridional circulation, the dryness climatology of Sahara and Northwest China deserts is investigated and compared. It is shown that in DJF, descent of local meridional circulation dominates the two deserts and very dry climate is unavoidable although the relative wet season is weak over the northern part of Sahara due to Mediterranean climate. While in JJA, there is ascent over the two deserts especially over Northwest China. Such ascent can explain the rainy season in south part of Sahara and Northwest China deserts. However, it is the local meridional circulation that takes strong and dry northerly from higher latitudes. The northerly either takes little moisture to the centers or prevents deep and strong convection over the centers. Such local meridional circulation leads to the dry climatology over the two deserts.

Key words: Deserts, Local meridional circulation

1. Introduction

There are many very dry areas over the Northern subtropics such as Sahara, Central Asia and Northwest China. A descriptive zonal mean meridional circulation mechanism in many meteorological textbooks explains that the descent branches of both Hadley and Ferrel circulations cause the dry climate over these areas. However, there are also many very wet areas like monsoon region and Florida everglades with same latitude as the deserts and these wet areas apparently could not be explained by the zonal mean meridional circulation. Charney (1975) proposed a biosphere– radiation mechanism to explain the desertification of Sahara. The over–grazing in this area leads to the enhancement of albedo that causes more net heat loss and stronger descent. The descent further strengthens the desertification. However, the desert center does not even have any biosphere and such mechanism is not

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appropriate for it.

Rodwell and Hoskins (1996) (hereafter RH) found that the center of descent is located in the Mediterranean and much more northward than that of Sahara desert especially in JJA season. They proposed a monsoon–desert mechanism that strong diabatic heating over summer monsoon area stimulates a westward propagating Rossby wave which produces warm structures over the dry regions. The mid–latitude westerly interacts with the warm structure and induces strong adiabatic descent. Such descent provides a severe dry climate for the deserts such as Kyzylkum and Sahara areas. However, they have not mentioned how the northward descent in the north leads to the Sahara desert in the south especially in JJA season.

There is another desert over Northwest China. Xue (1996) carried out a series of numerical experiments to study its impact on regional climate while its formation mechanism has not been paid attention to. Moreover, in either Charney's or RH's mechanism, the dryness over deserts is thought to be specified. Although the annual rainfall in these desert areas does be very weak, it still has relatively rainy and dry seasons. This study is intended to analyze the rainfall distribution and corresponding local meridional circulation over the Sahara and Northwest China deserts. All the general circulation data including vertical pressure velocity are from NCAR / NCEP reanalysis 1958–1997. Section 2 shows the rainfall characteristics over the two deserts. The local meridional circulation over the two regions is given in Sections 3 and 4. Summary and discussion are stated in Section 5.

2. Rainfall distribution

Based on Xie and Arkin (1997) monthly precipitation data from January 1979 to December 1997, the annual mean rainfall over part of Northern subtropics is shown in Fig. 1. Only contours with values less than 200mm are displayed and the thick dark line represents 50 mm.

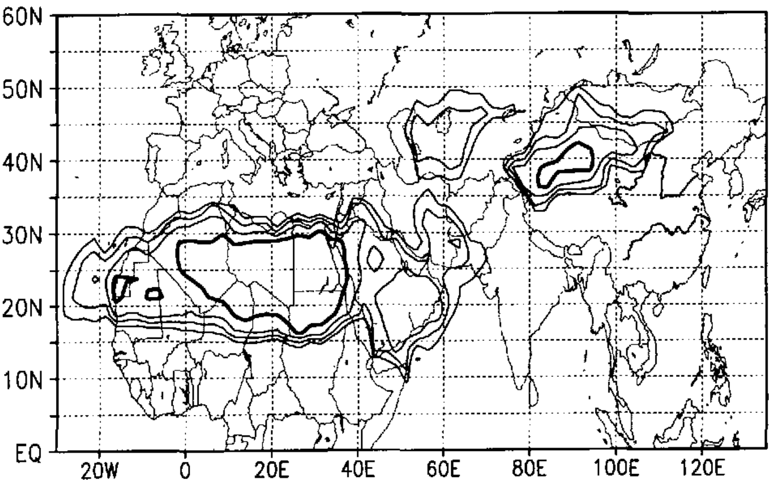


Fig. 1. Climate annual rainfall over dry areas. The thick dark line represents 50 mm and only contours with values less than or equal 200 mm are displayed with intervals of 50 mm. Data from Xie and Arkin, 1979–1997 mean.

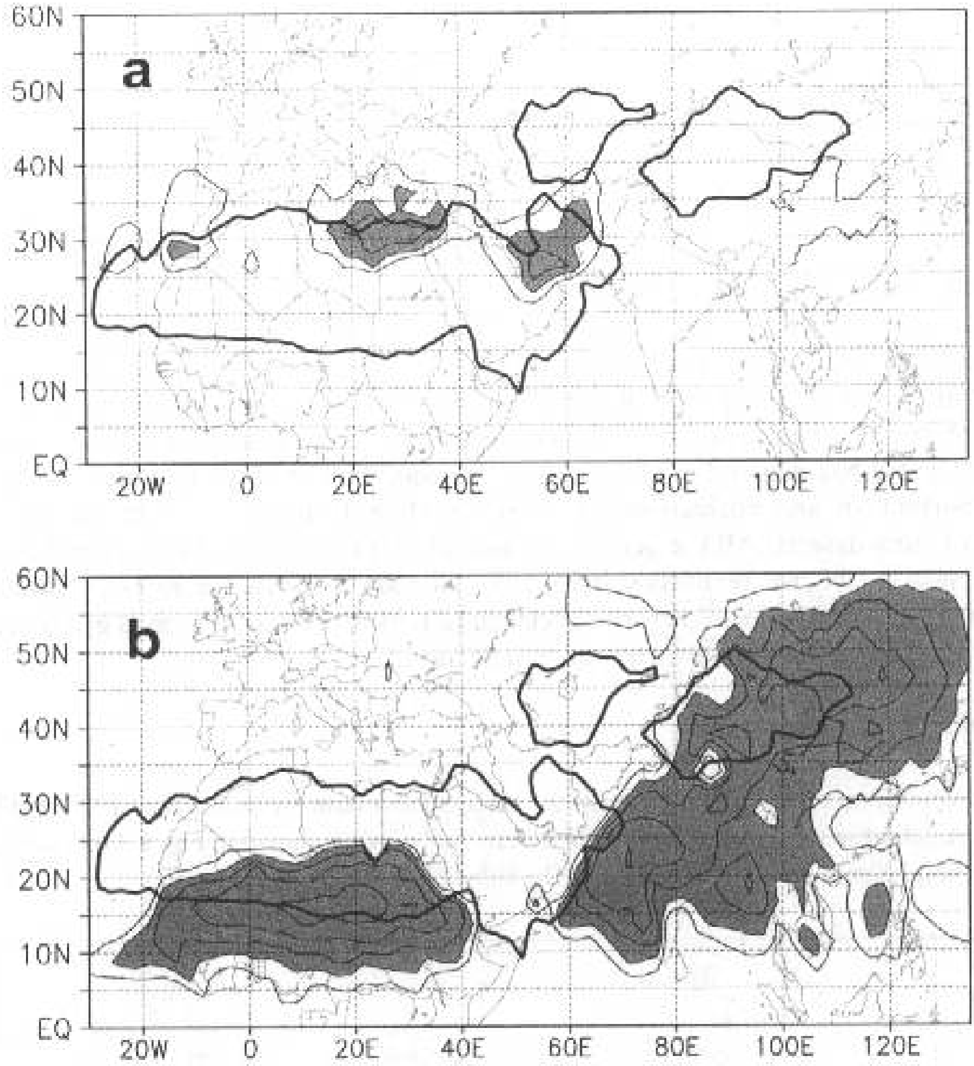


Fig. 2. Seasonal rainfall percentage to annual mean in DJF (a) and JJA (b) respectively. The thick dark curve is 200mm annual rainfall isoline. Contours greater than or equal 40% are displayed and shaded areas are greater than or equal to 50%, and the intervals are 10%. Data source is the same as in Fig. 1.

It is very clear that there are very dry centers with annual rainfall less than 50 mm over Sahara and Northwest China deserts. However, the ranges of the two deserts are very different. The 200 mm contour over the Sahara desert covers from about 15°N to 35°N, while it covers from 33°N to 50°N over Northwest China. And the Sahara desert is much larger than the Northwest China desert.

The seasonal rainfall percentage to annual mean is displayed in Fig. 2a (DJF) and Fig. 2b (JJA). Over 50−80% rainfall takes place in JJA season in the south part of Sahara and most of Northwest China deserts as shown in Fig. 2b. While in the north part of Sahara, about 40−60% rainfall concentrates in DJF season as in Fig. 2a.

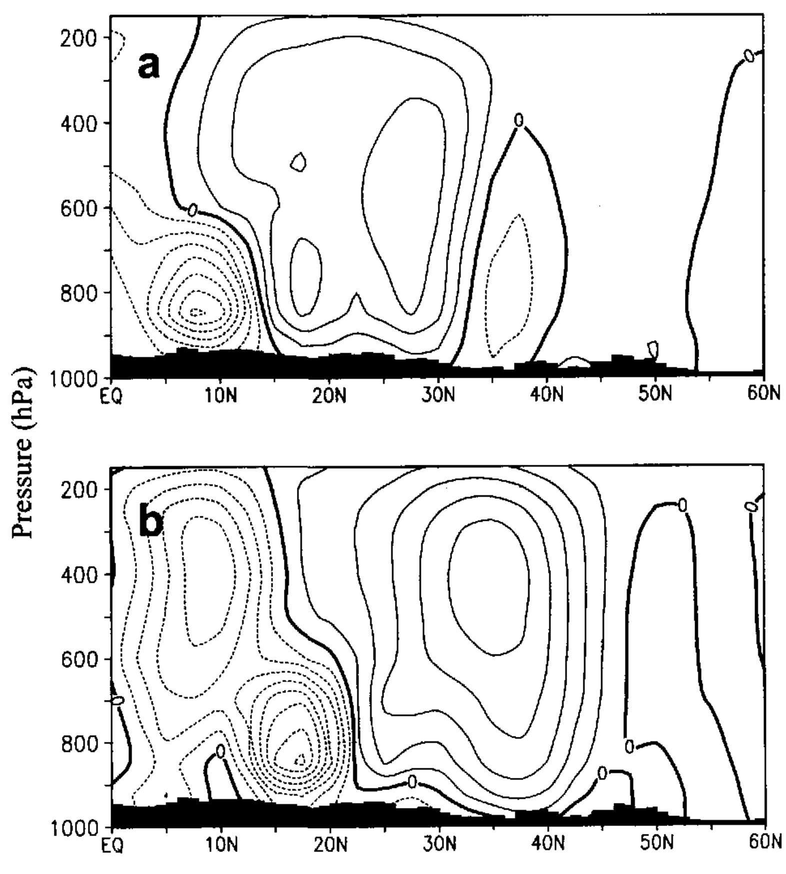
3. Local meridional circulation over Sahara

For the rainy seasons of Sahara and Northwest China deserts are JJA or DJF, the following discussion of local meridional circulation mainly focuses on these two seasons.

Figure 3 is pressure vertical velocity and local meridional circulation along 20°E. Figure 3a is for DJF. It is very clear that descent (region between two zero lines over lower latitude) dominates from about 15°N to 33°N in layers from 1000 hPa to 700 hPa. It covers almost the whole Sahara deserts. The descent is a little stronger near surface than aloft. To the south and north of descent areas, there are two ascent regions. The southern ascent region is much stronger than the north one and they correspond to the ascending branches of local Hadley and Ferrel circulations.

Figure 3b is the same as Fig 3a but for JJA. Besides the apparent seasonal transition of the ascending and descending centers, the strength of these centers is also different from that in DJF in Fig 3a. The descent region gets stronger and much more northward than that in DJF, which covers from about 22°N to 45°N. The southern ascent center corresponds to the ITCZ over Central Africa and is much stronger than its DJF counterpart. While the north ascent area gets even more northward and weaker than that in DJF. It should be noted that there is shallow ascending from about 23°N to 35°N, which covers the most part of Sahara deserts as in Fig. 2. Such ascent originates from very hot desert surface.

Figures 3c and 3d show the origin for the ascending and descending air in DJF and JJA. They are streamlines of southerly and vertical velocity. It is apparent from Fig. 3c that there



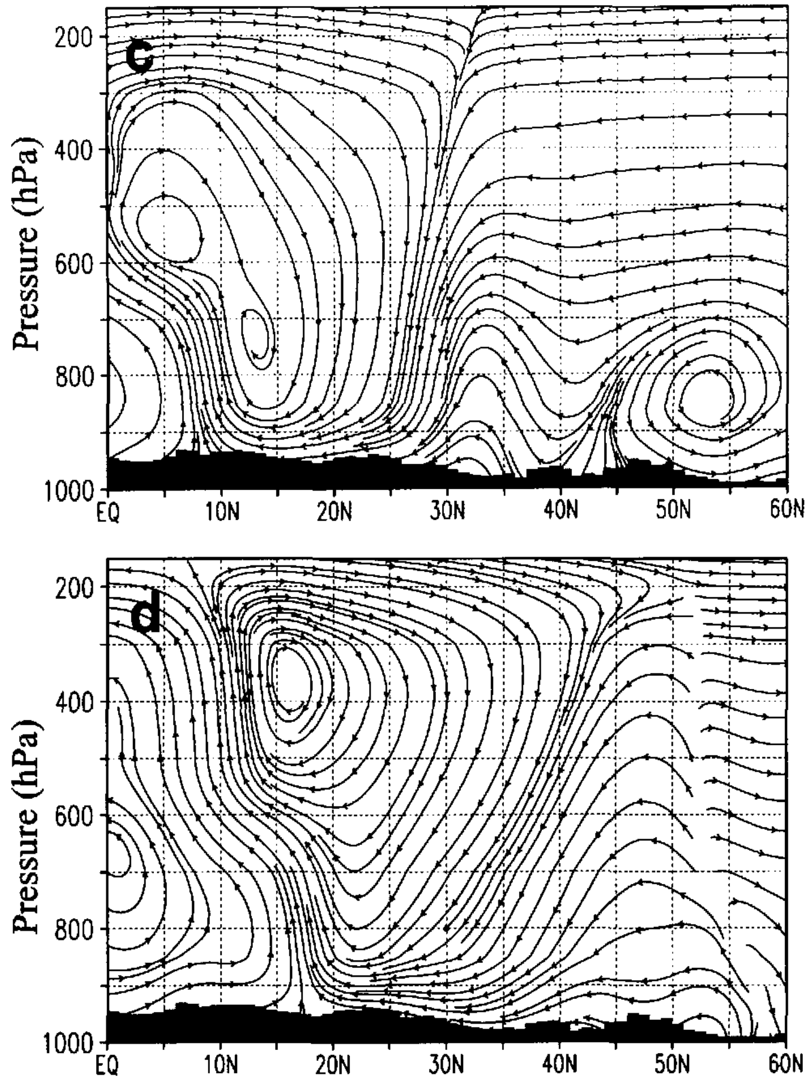


Fig. 3. Seasonal pressure vertical velocity (a, b) and local meridional circulation (c, d) along 20°E (averaged from 0° to 40°E), (a) and (c) are for DJF, while (c) and (d) are for JJA. Shaded area is topography along 20°N. Contours with negative values are dashed and positive values are solid. The thick dark isoline represents the zero line.

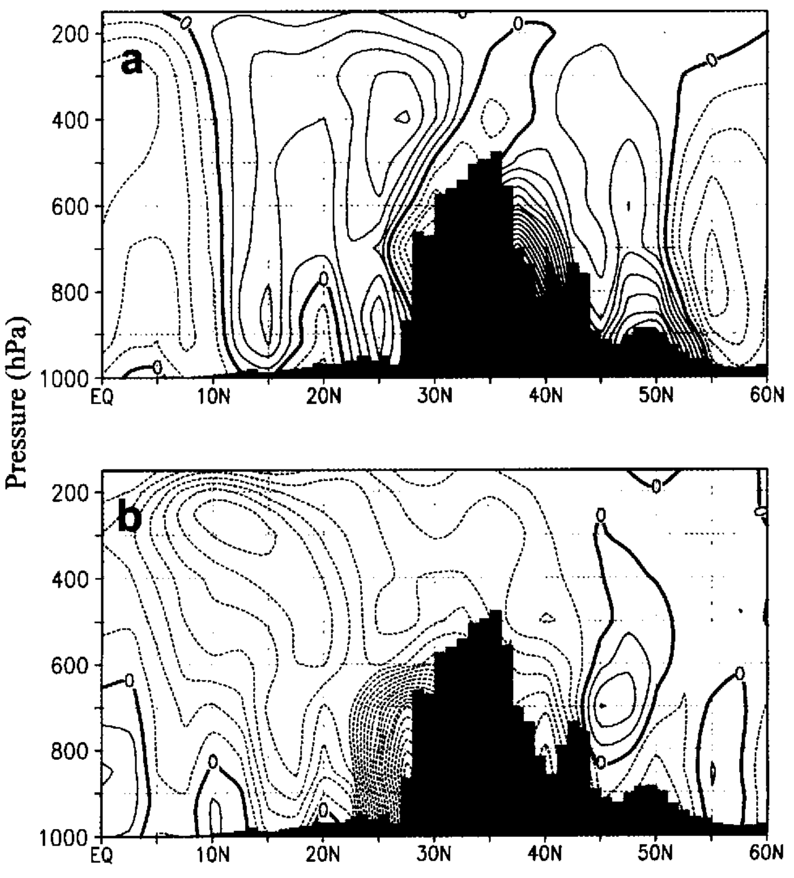
are two local meridional circulations along 20°E (averaged from 0° to 40°E). One ascends at 5°N–10°N and descends at 25°N–30°N. The other cell originates from higher latitudes and also descends at 25°N–30°N. Such circulations are typical Hadley cell and Ferrel cell. Over the Sahara desert, the descent center is located in its north part and arid air dominates its south part. Little rainfall in DJF is unavoidable. The annual mean local meridional circulation is very similar to Fig. 3c (figure not shown). Such distribution determines the arid climatology over the Sahara desert.

The local meridional circulation in JJA over Sahara desert is shown in Fig 3d Although there is only one closed cell over the desert, its structure is still not good for the in situ rainfall. From 25°N to 40°N, descent dominates from surface to 300 hPa wherever the flow originates from. Such strong and uniform descent mainly leads to the dryness under. The strong ascent branch shown in figure 3b is also detectable around 20°N in figure 3d. The south flank of the ascent fills with air from the tropics while the north one dominates air from upper altitude and higher latitudes. It is natural that ITCZ is located to the south of 20°N, while desert to its north.

4. Local meridional circulation over Northwest China

The Northwest China desert has also little annual rainfall and the rainy season is mainly in JJA. However, the local meridional circulation is very different from that over Sahara especially during its rainy season.

Figures 4a and 4b are belt–averaged vertical pressure velocity along 85°E (averaged from



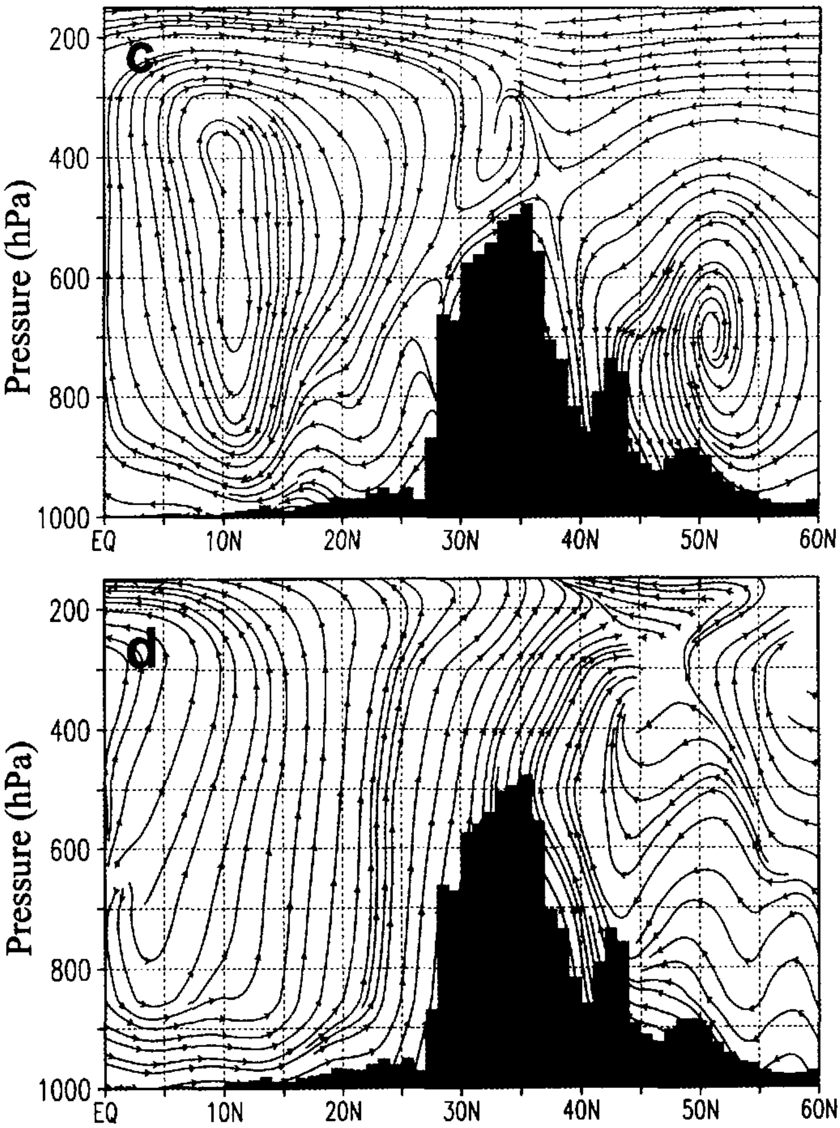


Fig. 4. Seasonal vertical pressure velocity (a, b) and local meridional circulation (c, d) along 85°E (averaged from 75 to 95°E), (a) and (c) are for DJF, while (c) and (d) are for JJA. Shaded area is topography along 85°E. Contours with negative values are dashed and positive values are solid. The thick dark isoline represents the zero line.

75°E to 95°E, which covers the whole desert center). The desert covers from about 30°N to 45°N as shown in Fig. 1. Figure 4a is the vertical velocity in DJF. Over the whole desert, descent dominates. However, it is totally opposite in JJA as shown in Fig. 4b. Ascent covers almost the whole desert area. Such ascent might lead to rainfall.

The local meridional circulations corresponding to Figs. 4a and 4b are shown in Fig. 4c and 4d respectively. Typically, there are two cells in DJF as in Fig. 4c. Over the desert area, descent dominates. It is the descent branches of Hadley circulation cell in lower latitudes and Ferrel circulation in higher latitudes. Such circulation is similar to the annual mean (figure not shown). Although ascent dominates the whole desert in JJA, the flow from the tropics is hindered by the Tibetan Plateau and the ascent totally originates from higher latitudes. The arid flow cannot take much rainfall over the desert although there is apparent ascent over the desert.

5. Summary and discussion

The Sahara and Northwest China deserts share similar annual rainfall characteristics, while their rainy seasons are very different. In the south part of Sahara and Northwest China deserts, rainfall mainly takes place in JJA. There is little rainfall in DJF in both deserts although the north part of Sahara has comparatively more rainfall than other seasons.

The local meridional circulation leads to the arid climatology over the two deserts. However, the circulation is different in DJF and JJA. There are typical Hadley and Ferrel cells over both deserts in DJF, which takes an arid winter there. In JJA, the strong and uniform descent over most north part of Sahara determines its dryness. Although there is shallow ascent near surface in its south, the air there originates from higher altitude and latitudes and dryness also takes place.

Over Northwest China desert in JJA, although there is uniform ascent, the flow from the tropics is hindered by the Tibetan Plateau and the ascent originating from higher latitudes still cannot take much rainfall then. Nonetheless, it does take a rainy season.

If the Tibetan Plateau is taken off, will the Northwest China desert get much wetter? It is an interesting topic for numerical experiments.

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局地经圈环流和沙漠

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摘　要

应用 Xie 和 Arkin 降水资料和 NECP / NCAR 再分析资料，研究了撒哈拉和中国西北沙

漠地区的干旱气候。结果表明，尽管该两区域都有在年降水量少于 50mm 的十分干旱的区域，但其年度特征却非常不同。在撒哈拉沙漠中心的南部地区和中国西北沙漠地区，超过 70%的降水出现在 6–8 月；而在撒哈拉沙漠中心以北地区，降水主要集中在 12–2 月。这种十分干旱的气候不能用 Channey 提出的生物圈–辐射效应加以解释。由于 6–7 月的强下沉中心远在撒哈拉强干中心的北部，其形成也不能用 Rodwell 和 Hoskins 提出的季风–沙漠机制予以解释。利用局地经圈环流的概念对两地干旱气候的分析和比较发现，局地经圈环流的下沉在 12–2 月支配着局地的垂直环流，导致干旱气候形成。这时撒哈拉北部的弱的、相对的多雨的气候是因受中海气候型影响所致。而在 6–7 月局地该为上升运动，其中尤以中国西北地区为显著。因此撒哈拉南部及中国西北的沙漠地区降水多集中在 6–8 月。不过与此上升运动相伴的是低空来之中、高纬的强而干的北风，它携带的水汽甚少，不利深对流发展。正是这种局地经圈环流导致了该两处干旱气候的形成。

关键词：沙漠，局地经圈环流