Arch. Met. Geoph. Biokl., Ser. B, 16, 316—346 (1968)

551.515(549—15)

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Weather Patterns in Southern West Pakistan

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With 7 Figures

(Received April 24, 1968)

Summary. Southern West Pakistan is an area of transition between the Indian summer monsoon system to the east and the winter cyclonic system of southwest Asia to the west. As a transition area, it receives scanty, unreliable rainfall averaging less than 10 in. (254 mm) per year from several storm types. Six main weather patterns cross the region: the large subtropical anticylonic high pressure cell which predominates most of the year; western depressions originating over the Mediterranean Sea; Arabian Sea cyclones; local thunderstorms and dust storms; a modified monsoon pattern; and eastern depressions originating over the Bay of Bengal or central India. A discussion of the physical and synoptic characteristics for each weather pattern and storm type is presented and summary charts of the weather patterns are included.

Zusammenfassung. Das südliche Westpakistan ist ein Übergangsgebiet zwischen dem indischen Sommermonsunsystem gegen Osten und dem winterlichen Zyklonalsystem von Südwestasien gegen Westen. Als Übergangsgebiet erhält es von einzelnen Stürmen nur geringen und unregelmäßigen Regen, der in der Jahressumme durchschnittlich weniger als 10 inches (254 mm) beträgt. Sechs verschiedene Wettersituationen durchqueren die Gegend: die ausgedehnte subtropische antizyklonale Hochdruckzelle, die während des größten Teils des Jahres vorherrscht; westliche Depressionen aus dem Mittelmeerraum; Zyklonen aus dem Arabischen Meer; lokale Gewitter und Staubstürme; eine modifizierte Monsunlage; sowie östliche Depressionen, die aus dem Golf von Bengalen oder aus Zentralindien stammen. Für jede dieser Wetterlagen und Sturmtypen werden die physikalischen und synoptischen Züge diskutiert und durch summarische Karten der Wettertypen dargestellt.

Résumé. Le sud du Pakistan occidental est une région de transition entre le système indou de la mousson d'été à l'est d'une part et le système des cyclones d'hiver de l'asie du sud-ouest à l'ouest d'autre part. Comme zone de transition, cette contrée ne reçoit que des précipitations faibles et irrégulières provenant de quelques ouragans, précipitations qui n'atteignent pas 10 pouces (254 mm) en moyenne annuelle. On distingue six types de temps dans cette région: La cellule anticyclonique subtropicale qui domine durant la plus grande partie de l'année; des dépressions venues de l'ouest, c'est à dire du bassin méditerranéen; des cyclones de la Mer d'Arabie; des orages locaux et des tempêtes de sable; une situation de mousson modifiée; des dépressions venues de l'est, c'est à dire du Golfe du Bengale ou de l'Inde centrale. On discute pour chacune de ces situations les traits caractéristiques des points de vue physique et synoptique. On les représente en outre au moyen de cartes générales.

I. Introduction

In 1950 H. H. LAMB [1] classified types and spells of weather into a series of patterns, based primarily upon cyclonic and anti-cyclonic wind patterns, for the British Isles. Similar techniques have been applied to other parts of the world, but few studies along these lines have been made for southern Asia.

The region which was selected here for detailed study was the southern portion of Baluchistan and Sind, West Pakistan, and proved to be of particular interest because its eastern part is a transition zone between the Mediterranean type of winter rainfall to the west and the monsoon summer rainfall to the east over India. The objective of the research was to discover a method which would give a more realistic picture of the climate of this area without overemphasizing the statistics of individual stations. The study is based on records from the Meteorological Departments in West Pakistan and Iran and on personal field notes taken by SNEAD [2] while in southern West Pakistan.

II. The Region Selected for Study

The desert region selected for study stretches from the border of India, west across Sind and Baluchistan to the Zagros Mountains of Iran. Most of this area has an average annual rainfall under 10 in. (254 mm) (Fig. 1), although a few localities, because of their greater elevation or because of exposure to more moist winds, receive 20 to 40 in. (508 to 1016 mm) of precipitation per year. While Karachi receives on the average 9 in. (229 mm) a year, most of the stations farther west record no more than 4 to 5 in. (102 to 127 mm) of rainfall per year. However, during some years a climate station will not record a single drop of rain. In other years as much as 24 in. (610 mm) will fall from only two or three storms; a single cloudburst may drop as much as 4 in. (102 mm). The erratic nature of the rainfall is summarized in Table 1 [3].

Table 1. *Variability of Rainfall in Inches and Millimetres*[1]

Station	Average	Minimum Recorded	Maximum Recorded
Karachi, West Pakistan (100 year record)			
Average annual rainfall	9.00 (228)	0.47 (11.9) (1871)	28.00 (711.2) (1869)
Rainiest month (July)	2.63 (66.8)	0.00	15.44 (391.2) (1934)
Driest month (November)...	0.03 (.76 mm)	0.00	0.52 (13.2) (1928)
Las Bela, West Pakistan (10 year record)			
Average annual rainfall	8.00 (203.2)	1.59 (40.4) (1931)	19.43 (492.8) (1914)
Rainiest month (July)	2.00 (50.8)	0.00	10.27 (260.8) (1944)
Driest month (November)...	0.00	0.00	1.53 (38.9) (1914)
Sonmiani, West Pakistan (40 year rekord)			
Average annual rainfall	4.83 (122.7)	0.10 (2.5) (1951)	24.29 (629.6) (1944)
Rainiest month (July)	1.54 (39.1)	0.00	13.89 (352.8) (1959)
Driest month (November)...	0.03 (.76)	0.00	0.91 (23.1) (1947)
Ormara, West Pakistan (10 year rekord)			
Average annual rainfall	6.00 (152.4)	0.55 (13.9) (1950)	16.99 (431.5) (1944)
Rainiest month (January) ...	2.00 (50.8)	0.00	6.27 (159.2) (1943)
Driest month (November)...	0.00	0.00	0.12 (3.0) (1954)
Panjgur, West Pakistan (30 year rekord)			
Average annual rainfall	4.00 (101.6)	1.24 (31.5) (1946)	15.68 (398.2) (1944)
Rainiest month (February)...	0.00	0.00	2.48 (62.9) (1935)
Driest month (October)	0.01 (.25)	0.00	0.16 (4.0) (0923)
Jask, Iran (10 year record)			
Average annual rainfall	4.00 (101.6)		
Rainiest month (January)....	1.00		
Driest month (June)........	0.00		

[1] Pakistan Meteorological Department Records, Karachi.

Although rainfall is extremely variable, set types of weather occuring thoughout the year can be grouped into six main patterns. The purpose of this paper is to identify the patterns of weather and to describe the reasons for their occurrence by using a method of synoptic comparison of the characteristics associated with each weather type.

III. Seasonal Divisions

Southern West Pakistan has four pronounced yearly seasons based mainly upon temperature. The length of each season varies from year to year, depending upon the amount of cloud cover, but the following time periods are recognized by the Pakistan Meteorological Department.

The winter season is long, lasting from early November to the end of March [4]. Although a few storms may occur, the winter season is generally a time of cloudless, warm (70 to 80° F)

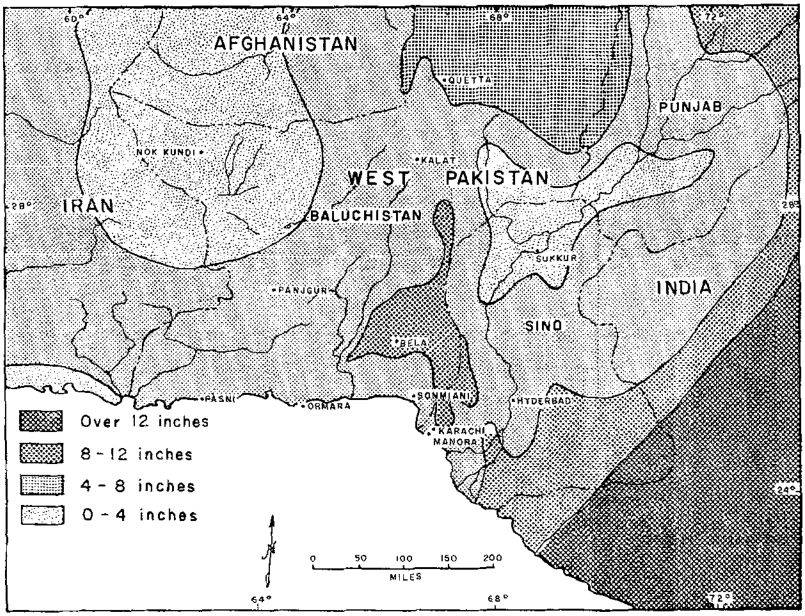

Fig. 1. Average annual rainfall

(21—27° C) days with cool nighttime temperatures. Frost occasionally occurs in the interior desert basins, and snow falls on the high mountains around Quetta, but near the coast nighttime temperatures remain in the 50° F (10° C) range.

Temperatures begin to climb rapidly in March, and stations are recording temperatures over 90° F (32° C) by April. April, May, and June are called the hot season because the highest temperatures are recorded in May. Intense radiation takes place under clear skies, and consequently, this is a very hot, dry, and dusty time of year.

The months of July and August are the so-called monsoon season, which is in essence a modification of the true monsoon system over India. A low cloud cover which moderates temperatures but adds humidity to the air, moves in over eastern Baluchistan, Sind, and the Makran coastal areas in mid-June and often lasts until mid-September. The months of September and October are called the fall transition season, but temperatures often climb to over 100° F (38° C) in October because the cloud cover leaves. The winter season begins in November when a cooling trend sets in.

To the east and west of southern West Pakistan the seasons are more pronounced. Over the Thar Desert in India the monsoon system is stronger, and the winter is a well-defined long dry season.

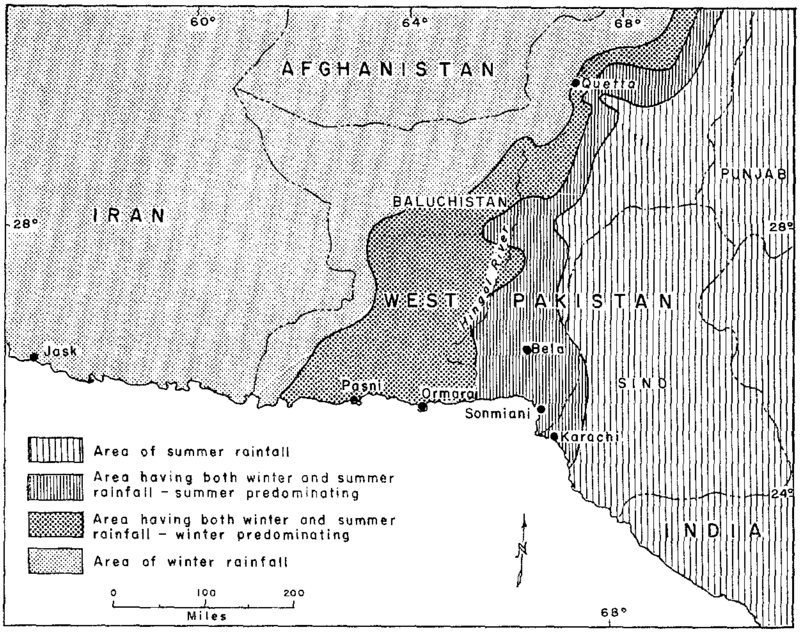

Fig. 2. Distribution of summer and winter rainfall

To the west, over Iran and in the interior western part of Baluchistan, the monsoon cloud cover is absent, so the seasonal division corresponds to the heating and cooling normal for a latitude of 25 to 30° North. The summer months — June to August — are hot, dry, and dusty.

The seasonal divison of rainfall for southern West Pakistan is shown in Fig. 2 [5]. Nearly all of Sind and the eastern part of Baluchistan have a pronounced summer monsoon maximum coming in June, July, and August. This line conforms to the eastern slopes of the Kirthar and Sulaiman Mountain ranges which act as a barrier to storms from the east [6]. Iran and the western part of Baluchistan have a winter maximum coming from November to March with very little summer precipitation. Central Baluchistan is a region having both winter and summer rainfall with a slight winter maximum, while a thin band in eastern Baluchistan is an area having both winter and summer rainfall, but with a slight summer maximum. Table 1, showing the variability of rainfall, and Table 5, indicating the number of storms reaching Karachi and Jask, illustrate further the differences found on the east and west sides of West Pakistan.

IV. Characteristic Weather Patterns

1. Type 1: The Subtropical Anticyclonic Pattern

Throughout the year the dominant weather pattern is a large high pressure system which remains stationary over most of southwest Asia. During the monsoon months, from mid-June to mid-

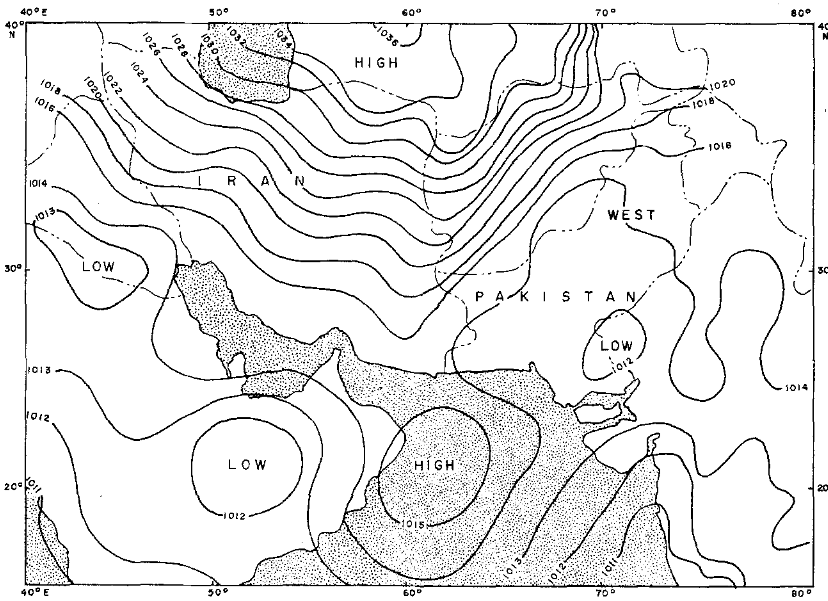

Fig. 3. Anticyclonic High Pressure Pattern over Iran on October 20, 1959 (Pakistan Daily Weather Map, Pakistan Meteorological Department, Karachi)

September, this system will break down in eastern Baluchistan and Sind to allow an influx of warm, moist, maritime monsoon air. Often the daily weather map will show most of southwest Asia covered by one large high pressure cell (Fig. 3). It is between or on the flanks of this constantly recurring climatic pattern that other weather types take place.

a) Physical Characteristics

Temperatures within the subtropical anticyclonic pattern show a very slow, almost imperceptible change from one day to the next. Daily ranges are higher than monthly or seasonal ranges. From mid-September through October, daytime maxima often reach into the 90's^0 F (above 32^0 C) but in November, December, and January, there is a gradual cooling, and daytime temperatures are in the 70's^0 F (above 21^0 C) while nighttime temperatures may drop to freezing in interior basins because of radiative cooling under clear skies. By February, temperatures begin to rise, and in March daytime maxima are back up into the high 80's^0 F (above 27^0 C). April, May, and the first half of June are extremely hot months in this region. Interior desert basins will reach 118 to 120^0 F (48 to 49^0 C). Even the nights are very warm because increased humidity and dust in the air retard the long wave terrestrial radiation. The spring months, the so-called summer season, are the most uncomfortable of the year, not only because of the constantly high temperatures and great monotony of climate, but also because of the haze and local dust storms. All life seems to be in a dormant stage awaiting the cooler, moister weather due to arrive over most of the Indian Subcontinent.

In the interior, winds are gentle and variable during the entire subtropical anticyclonic pattern. Their predominant direction is north-northeast, occasionally shifting to west and northwest if a small high pressure cell passes over the region. These smaller cells often result in the flow of cooler winds. When these winds are dusty, dust storms result. The midwinter months have very little wind. For interior basins, the mean number of calm days in December is 25. Because of the increased heat in the interior, a sea breeze begins along the coast by mid-March and occurs almost daily until October. By June the coastal winds become stronger, and the diurnal sea breeze becomes submerged in the general monsoon flow [7].

When the subtropical anticyclonic pattern predominates, clouds are almost nonexistent. In some years no clouds are seen from mid-September until January. Then in January a few cirrus will appear indicating a disturbance is moving across Iran into Baluchistan. The northern parts of this region are cloudier than southern parts because strong westerly winds, between 30 000 and 40 000 feet (9144 and 12 192 m) steer more storm tracks across northern Iran and West Pakistan. The jet stream moves to the northern part in midwinter with two main branches: one track moves south of the Himalayas while the main one crosses north of the Himalayas. The dynamics of the jet stream may directly influence the existence of the anticyclones [8].

b) Synoptic Characteristics

Southern Baluchistan, 25 to 30^0 north of the Equator, is in the normal latitude for subtropical anticyclones and for the deserts which develop because of subsidence [9]. The desert of West Pakistan is a continuation of the Saharan, Arabian, and Iranian deserts and extends east to the Thar-Rajputana desert of India. The usual formation of the monsoon system at this latitude is more of a climatic anomaly than the development of a desert. Since the subtropical anticyclonic system is such a dominant system during most of the year, the important question that arises is how can storms invade and cross this area, particularly in winter.

It appears that the subtropical anticyclonic system is best developed at about 10 000 feet (3048 m) from March until November. The so-called "low" which forms during April and May, centered over the Indus Basin and the Thar Desert, is thermally induced. This "low", however, has been found to be very complex because the mean height of the 500 mb isobar is lower over the Thar Desert than anywhere else along latitude 25 to 30^0 north. The maritime tropical monsoon air that does reach this region comes in close to the surface, bringing humidity and a partial cloud cover but very little precipitation. The intense heat and high humidity close to the surface make the Kacchi Desert of northern Sind almost unbearable during the months of June, July, and August. Farther west in Baluchistan temperatures are high, but not as much moist air penetrates the area.

The total mass of humid air which crosses the coast from the Arabian Sea especially in June, July, and August is small and variable. Enough moist air, however, reaches the Indus lowlands and foothills of Baluchistan from both the Arabian Sea and the Bay of Bengal to give this region a small, but well defined July maximum. The boundary between a monsoon maximum rainfall and a winter-spring maximum occurs in eastern Baluchistan about 100 miles (160.9 km) west of Karachi (Fig. 2). The monsoon maximum over northern India is a result of the displacement of the Intertropical Convergence Zone 5 to 10^0 farther poleward than to the west over West Pakistan and Iran [9].

Subtropical anticyclonic cells continue as the main winter pattern, but waves of disturbances move across southern Iran and

Baluchistan when the anticyclonic system is displaced. The anticyclonic "highs" bring relatively cool, continental air from eastern Europe and western Asia across the highlands onto the Indus lowlands. In winter in the northern part of Iran and Baluchistan, the larger well-developed depressions are followed by cold high pressure air masses, modified c^p (continental polar) air which spreads south and east in the form of true cold waves. By the time these cold waves reach southern Iran and Baluchistan, they have been greatly modified by distance and mountain barriers, but disturbances even as far east and south as Karachi will cause temperatures to drop several degrees. Possibly, the erratic nature of winter precipitation exists because the waves of fresh, dry continental air do not move across Baluchistan as fronts but rather as isolated cells broken off from the main disturbance to the north. The introduction of this slightly cooler air from northern latitudes in addition to less radiation gives this region its cool season. This cooler air also helps to act as a trigger that condenses the little moisture that is available. Most of the storms which enter this region are short lived. In 1 or 2 days, or in some cases in a few hours, the desert will return to the subtropical anticyclonic pattern of clear days and low humidity. Thus, between September and June southern Baluchistan may be under the influence of anticyclonic subsiding air 95 per cent of the time; interior parts of Baluchistan, which miss the monsoon season, may be under this one type of climatic pattern an entire year as few western depressions move into this region.

2. Type 2: Western Depressions (Winter Cyclonic Storms)

Beginning in November at the end of the transition period, a series of cyclonic storms called western depressions move from the Mediterranean region across southwest Asia toward India. These storms follow at least three main tracks. Those following a southern track into southeastern Iran and Baluchistan usually bring only 4 or 5 in. (102 or 127 mm) of light precipitation per year which accounts for the winter rainfall maximum in most of southwest Asia. Field investigations along the Makran coast indicate that the transition zone between a summer monsoon rainfall maximum and a winter cyclonic rainfall maximum takes place between the Las Vela Valley and Ormara in the vicinity of the Hingol River (Fig. 2). Since this is a transition zone, the line fluctuates widely from year to year.

A daily weather map in January will often depict a secondary cyclone forming as a breakoff from the primary storm track. The primary storm will move across Afghanistan and northern West Pakistan with more rainfall than the secondary storm which follows a more southerly route. However, if the secondary storm moves out over the Arabian Sea, it often picks up moisture and intensifies into

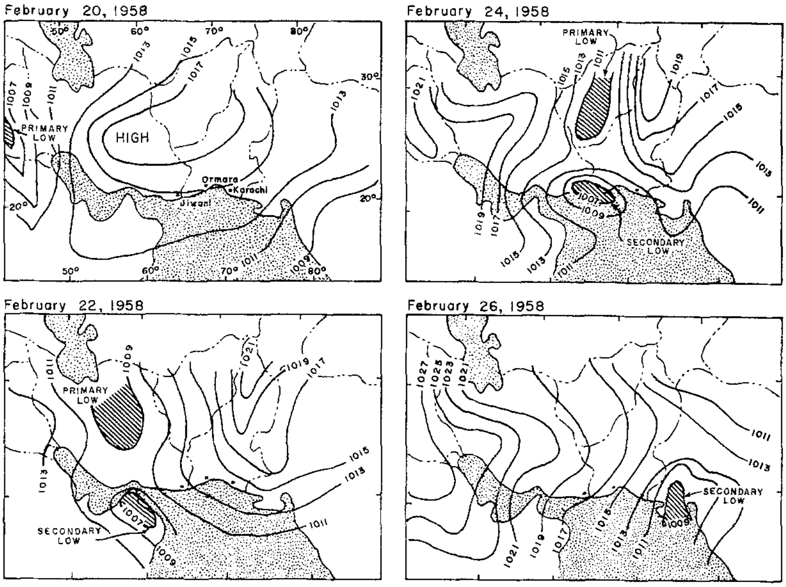

Fig. 4. Movement of a "Primary Low" (Winter Cyclonic Depression) and its accompanying "Secondary Low" across southern Iran and West Pakistan (Pakistan Daily Weather Maps, Pakistan Meteorological Department, Karachi)

several local gales and squalls. Although they are cyclonic storms with well-pronounced fronts over Asia Minor, many of these weak disturbances are difficult to follow because often their frontal characteristics break down as they move into southern latitudes.

a) Description of the Winter Cyclonic Storms Crossing Southern Iran and Baluchistan

The following is an account of a mild western depression observed by the author, as it crossed over the Las Bela coastal plain and Karachi between February 22 and 28, 1958 (Fig. 4).

During the afternoon of February 22, high cirrus clouds began to appear with southwest wind speed of 7 miles per hour (11.3 km per hour). The temperature climbed to 87^{0} F (31^{0} C) warmer than is normal for the data. Cirro-stratus, alto-stratus, and finally cumulus clouds developed in the afternoon.

On February 24, the skies cleared but a temperature of 87° F (31° C) continued. The barometer dropped from 1015 mb to 1007 mb, and winds speeds decreased to 4 miles per hour (6.4 km per hour) at Karachi airport. The whole area appeared to be in a "warm sector" with no welldefined fronts. The Meteorological Department reported that a western disturbance was moving rapidly across Iran with its trough, a secondary depression, extending to the Persian Gulf. By late afternoon on February 24 the primary depression had moved to the Quetta area bringing light rain and drizzle. The secondary depression over the north Arabian Sea brought 2.4 in. (61 mm) of rain to Jiwani, a coastal port, and 0.07 in. (2 mm) to Ormara (Fig. 4). On the morning of February 25, dark clouds began to form over the Las Bela coastal plain. The storm began with several flashes of lightning and a clap of thunder. In approximately 15 hours a total of 0.9 in. (23 mm) of rain was recorded at the Drigh Road Meteorological station in Karachi. The rain came as scattered hard showers and drizzle through the afternoon and evening. Winds at 8 miles per hour (12.9 km per hour) shifted from northeast to southeast and then back to northeast again. Temperatures dropped from 84° F (29° C) at noon to 75° F (24° C) in the later afternoon. Night temperatures on the 25th were 9° F (—12.8° C) cooler than on the 24th. For the next 3 days, temperatures slowly increased, winds shifted to the west-southwest, and white cumulus clouds, indicative of a could wave, slowly disappeared. This particular storm had many of the characteristics of a frontal passage.

Usually the effects of a western depression are not striking. The 0.9 in. (23 mm) of rain added only a little moisture to the very dry Las Bela soil, and the cooler temperatures lasted only a few days. However, when day to day changes in the climate are very small, any change in temperature, humidity, or cloudiness is significant [10].

A description from the India Weather Review for 1938 tells of a sudden squall on November 27, 1928, accompanied by blinding flashes of lightning and a torrential downpour of rain. The squall only lasted for 2 minutes, but the wind reached 35 miles per hour (56.3 km per hour). These sudden unpredictable squalls cause some damage, often plowing down houses and huts, cutting telegraph lines, uprooting trees, and at times capsizing fishing boats.

b) Synoptic Characteristics

For a number of years meteorologists were uncertain about the origin of western depressions [11, 12]. However, in 1913 Gilbert T. Walker [13] indirectly connected the cold weather storms of northern India with depressions from the Atlantic Ocean that crossed over the Mediterranean Sea to the Middle Coast. Tracing the individual storms was difficult because of the lack of stations in Afghanistan and eastern Iran. But, by setting up correlation coefficients for rainfall, snowfall, pressure, and temperature, there were strong indications that many disturbances did move on east to the Indian Subcontinent. More recent studies show that these depressions are very complicated because they are erratic and often lack a true frontal system.

M. S. Singh [14] makes the following conclusions concerning these storms:

1. Western disturbances need not necessarily be considered moving from the west, as had been emphasized in past writings.

2. The movement and the intensification of western disturbances are controlled by the upper tropospheric circulation (lowest, 300 mb level) in the Middle East and the Southern Russian regions.

3. For the prediction of intensification of any western disturbance the position and the configuration of the upper air trough in the westerlies in the middle East as well as those of any jet stream embedded in it in relation to the surface low have to be watched.

4. As for the development of blocking situations in the upper tropospheric westerlies, it appears that the confluence of warm and cold air masses downstream of a growing ridge is an important factor. It is a process by which both the ridge and the trough grow in intensity and warm and cold air masses are pulled more and more to the north and south respectively.

5. This process of blocking stops as soon as any of the warm or cold air supply is cut off resulting in the destruction of the confluence.

For northwest India in the winter months, December to April, about seven out of every ten disturbances are continuations of depressions from southern Europe [13]. On the average, three or four of these disturbances reach southern Baluchistan. It was also found that disturbances pass more often through southern Iran and Baluchistan during the mid-winter months, December to March, April, and May. The displacement of the storm track farther north in the early spring seems to be governed by the northward movement of the Intertropical Convergence Zone (I. T. C.) [15, 16, 17].

The reason that winter western disturbances are able to cross southern Iran and Baluchistan while monsoon and Arabian cyclones are either blocked, diverted, or steered toward the eastern and southern sides appears to be related to seasonal differences in the size and intensity of anticyclones. From April until November the anticyclonic high pressure system is pronounced and forms a nearly stationary well-developed capping over the modified monsoon air which moves in from the coast close to the surface. From November through March, however, the high pressure cells are more broken up. Instead of one or two large systems, it consists of a series of small high pressure cells which follow one another from west to east. Between these highs the western disturbances form and move. It appears that toward the south in southern Iran and Baluchistan the highs may be large with little spacing between. As a result fewer depressions can form. These ideas are largely hypothetical for the picture is very complicated with the jet stream having a steering effect upon the flow pattern. The flow pattern changes when an anticyclone is displaced from its prevailing position over the southern desert regions. When this occurs depressions are able to move freely into the region [14].

The question of the source of moisture for western depressions is not fully understood either. The depressions originating over the Atlantic Ocean or over the Mediterranean Sea have a good source, but much of this moisture is lost over the Levant States or against the highlands of western Iran. For southern Iran and Baluchistan, a disturbance lacks moisture if the storm center encounters moist monsoon air in pocket basins or river valleys or unless it passes over the Persian Gulf or Arabian Sea.

3. Type 3: Arabian Sea Cyclones

The Arabian Sea cyclones are much more severe than the winter cyclones, but occur considerably less frequently. These small tropical cyclones, which develop over the warm Indian Ocean, move north and west during the transition months of September and October and the summer months of May and June. Usually weather conditions over land are very stable during these periods, but every 3 or 4 years a storm will develop over the sea with winds 75 to 80 miles per hour (120.7 to 128.7 km per hour) around a deep, small low. Many of these storms lose intensity as they move to more northerly latitudes, but a few reach the coast. Between 1847 and 1959 about sixteen of these storms were officially plotted (Fig. 5). As shown on the map, the paths of the cyclones are very erratic and difficult to follow. Although most of the disturbances curve as they move farther and farther north, some have been found to move on a straight course directly toward a land area [18, 19].

The high winds create very rough seas and with the high tides cause disasterous coastal flooding. Fortunately, these storms do not penetrate very far inland, but when combined with another depression they can create some of the most intense rainfall that has ever occurred in the southern part of West Pakistan and Iran, bringing 2 to 3 days of continuous rainfall.

a) Description of a Particular Storm

The following is a condensed description of a severe tropical cyclone in the vicinity of Karachi between June 3 and June 6, 1967.

On June 3 there was disturbed weather in the Arabian Sea to the northwest of Bombay and on June 4 the storm had its center situated off the coast between Bombay and Karachi. The cyclone had still further developed on the 5th when the center moved northward being about 200 miles (321.9 km per hour) south of Karachi. On the 6th the center was close to Karachi where strong gales with wind speeds at 52 miles per hour (83.7 km per hour) were reported. At noon a gale with hurricane squalls was causing a tidal surge in the harbor at Karachi. The barometer reached its lowest reading 988.8 mb. In the afternoon the wind shifted to south-southwest, with squalls recorded at nearly 65 miles per hour

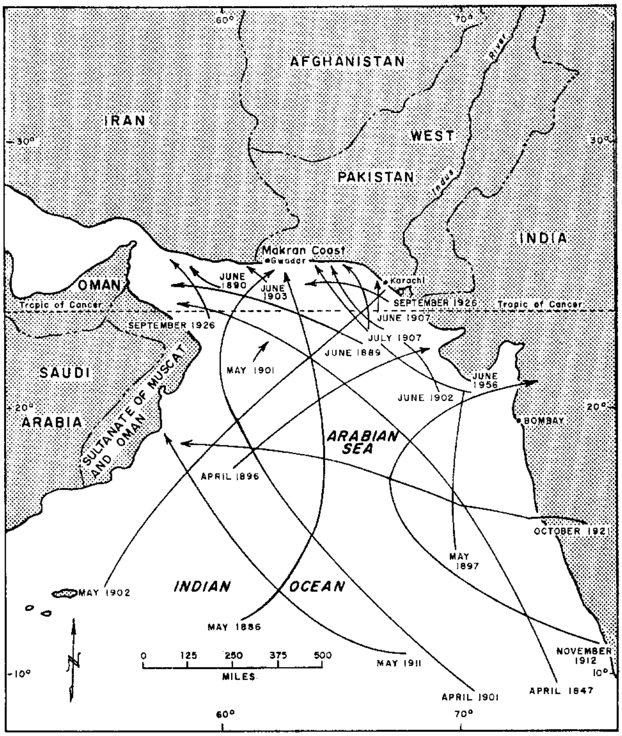

Fig. 5. Tracks of Major recorded Arabian Sea cyclones (1847 to 1956) (Adapted from C. W. Normand [18] and Records of the Pakistan Meteorological Department, Karachi)

(104.6 km per hour). In the evening the wind shifted to the west and the barometer had risen to 999.0 mb. The next day the weather moderated for the storm had passed inland and dissipated [20].

The author experienced a similar but more severe storm in late June and early July 1959, when over 8 in. (203 mm) of rain fell in 5 days in the region of Karachi. This storm is of particular interest because it joined with an early eastern depression moving west from the Bay of Bengal.

On June 24, 1959 a small tropical depression was discovered by ships in the Arabian Sea off the coast of Bombay. On June 26 and 27 this storm moved slowly north intensifying into a true Arabian Sea cyclone. At the same time far to the east a depression formed over the Bay of Bengal and began to move rapidly west across India, appearing to follow the path of the intertropical convergence zone which was situated over central India at this particular season of the year. On June 28 the Arabian Sea cyclone was situated southwest of Karachi and appeared to be moving northwest toward the western part of the Makran coast. But on June 30 the wind shifted to the northeast and during most of the day a large dust storm with winds up to 40 miles per hour (64.4 km per hour) moved across southern Sind. Local inhabitants suffered not only from the very fine dust brought from the Thar Desert but also from the sudden rise of temperatures to 101° F (38° C). There was great relief when around 7.00 p. m. thick, dark clouds burst over the entire city and torrential rains began to flood the urban area for the next 5 hours. By midnight intermittent showers totalled 1.15 in. (28 mm).

Normally, the 1.15 in. (28 mm) of rain which Karachi received from the Arabian Sea cyclone would not have been unusual, but on June 30 the Bay of Bengal eastern depression moving across central India was fast approaching the Karachi region. July 1 was a cloudy, windy day in Karachi. A total of 0.13 in. (2.5 mm) of rain fell mostly as short intermittent showers. On July 2, the eastern depression joined with the Arabian Sea cyclone resulting in unusually heavy rains. On July 2, 0.34 in. (8 mm) of rain fell, and during the next 2 days 2.53 and 3.53 in. (63 mm and 89 mm) of rain occurred, totaling 8.83 in. (224 mm) in 5 days. Considering that the average total annual rainfall for a 100 year period for Karachi is only 7.75 in. (196 mm) [21], this single 5-day storm produced more rain that Karachi would receive on the average in 1 year. Because of this storm, rivers flooded wide areas, washing out roads and bridges, and along the coast water collected in low places such as between coastal sand dunes.

b) Synoptic Characteristics

Arabian Sea cyclones are most frequent during the transition periods, April through June and September through December, before and after the onset of the monsoon season [22]. The true intense Arabian Sea cyclone, with a central eye and hurricane winds of more than 75 miles per hour (120.7 km per hour) will move long distances from the Indian Ocean across the Arabian Sea. It has been noted that as the storms move toward the coasts of Baluchistan and Iran, their paths appear to be subject to directional steering by the upper wind field over southern Asia. The strength and intensity of the high pressure system over the land influence the recurvature of many of these storms, as the high pressure influences the paths of hurricanes moving along the east coast of the United States [23].

The intense cyclones of hurricane nature develop and move entirely over water, making up about half of the disturbances crossing the Arabian Sea. Less vigorous storms, with poorly defined storm centers are known as depressions. The origin of these storms may be related to the very indistinct, but still prevalent, intertropical convergence zone which advances on a broad front north into India during the monsoon months. Toward the end of April the convergence zone penetrates far enough into the northern hemisphere to produce disturbances of tropical-cyclonic intensity both in the Bay of Bengal and the Arabian Sea. Some of these disturbances may become intensified by a last dying cyclonic depression moving east from the Mediterranean region or by an early eastern monsoon depression crossing central India.

The primary peak for all Arabian Sea storms is in May and June. A secondary peak of activity occasionally occurs when shear-produced cyclonic frontal waves follow closely upon the retreating intertropial convergence zone in September and October [24]. Most of these depressions, however, fail to reach the coasts of the northern Arabian Sea because upper air currents are strongly anticyclonic with winds off the land. Abnormally high temperatures prevail over southern Baluchistan when a storm or depression over the Arabian Sea causes an easterly flow of air off the Thar Desert and prevents the sea breeze from forming. For example, when the heat wave gripped Karachi from October 3 to 10, 1941, day temperatures stayed 6^0 F (3.3^0 C) above normal and reached a maximum of 109^0 F (43^0 C) [25].

The Arabian Sea cyclone is practically unknown in the cool season, when dry northeasterly winds cross the water bodies from the mainland of sounthern Asia. Cyclones are also rare during the southwest monsoon months, mid-June to mid-September, because strong winds of oceanic origin move steadily against the coasts [26].

CHOUDHURI, SUBRAMANYAN, and CHELLAPPA [27], in a study of Arabian Sea storms and depressions, found that in a 61 year period (1890—1950) a total of 140 disturbances were recorded in the Arabian Sea, of which true cyclonic storms numbered 63 and depressions 77. Because many of these storms dissipate over the sea, it is difficult to estimate the total number of storms forming each month or their frequency in hitting a particular land area. The storm paths, however, appear to reach the Rann of Cutch and Makran coast more frequently [28].

4. Type 4: Convectional Storms

In the spring and fall, extreme surface heating or a dying winter cyclone will result in the breakdown of the anticyclonic pressure system over the desert, enabling the buildup of large cumulonimbus clouds. Thunder squalls can occur in almost any month, but they are most numerous in June with usually one or two severe storms per year. In winter, a thunder squall may occur only once every 2 years. Often they fail to materialize because the stability associated with the anticyclonic pattern is well developed. When a passing disturbance such as a western depression capable of disrupting the upper inversion layer synchronizes in time with the maximum convectional conditions of the afternoon, sharp thunderstorms and squalls may occur. Perhaps, nearly all convectional storms can be correlated with one of the other types of weather patterns and even the jet stream may influence the development of large scale convection [29]. However, they are distinctive climatic type, particularly in the hot interior valleys. These storms are extremely localized and erratic, often affecting one part of a valley or mountain area and not another. They may last only a few minutes or up to one or two hours.

The high winds, heavy downpours of rain and in some cases hail, are often very destructive to crops even though they bring needed moisture. Small rivers, dry most of the year, can become raging torrents within a few hours. Often the precipitation that falls in the mountains flood streams which lead out onto the plains. In 1959 a local convectional storm in the mountains to the north of the Las Bela Valley flooded small streams 10 miles (16.1 km) away. Because these storms are usually small and extremely localized, they seldom bring appreciable amounts of moisture to the desert region as a whole. More often, extreme heating in the afternoon and convectional circulation of air results in a severe duststorm which will fill an entire valley. The dust sometimes extends to a height of 10 000 feet (3048 m) or higher.

a) Reasons for the Lack of Local Convectional Storms

There appear to be at least three main reasons why more convectional storms do not occur. The first is lack of moisture during most of the year. Although conditions for evaporation are good, there is little stored ground moisture or lakes to evaporate and feed cumulus clouds. Even during the monsoon months when moisture is carried inland from the Arabian Sea through the mechanism of the modified monsoon pattern, moisture is kept from rising because of a second main reason — the capping action of the inversion layer. This inversion layer is highest over the eastern part of Baluchistan and Sind and decreases toward the Iran border. Thus, thunderstorms are extremely rare in the interior of Baluchistan and in southern Iran except where orographic conditions prevail in the higher mountain regions. The extreme southeastern part of Iran has a low incidence of thunderstorms since the little rainfall there is comes during the dying western depressions.

A convectional storm can occur only when the inversion layer is broken and moisture can rise to over 10 000 feet (3048 m), a very rare occurrence over much of the desert region. In a few eastern Baluchistan valleys such as the Las Bela Valley, thunderstorms are more numerous, particularly during the monsoon months, when monsoon air pushes back the inversion layer resulting in turbulent conditions. Often towering cumulo-nimbus clouds are seen inland over the mountains or over very hot pocket valleys but climate stations, which are few and far between, do not pick up these local storms. Las Bela, located 80 miles (128.7 km) inland from the coast, records three times as many convectional showers as a coastal station such as Karachi. Table 2 indicates the number of thunderstorms for two coastal stations and the interior station of Las Bela.

Table 2. *Average Number of Days with Thunderstorms*

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Las Bela.........	0.4	0.6	1.6	2	3	3	4	3	1.3	0.1	0	0.3	19
Karachi..........	0.4	0.9	0.4	0.1	0	1.1	1.9	0.7	0	0	0	0.2	6
Ormara..........	0.3	0.6	0.9	0.3	0.2	0	0.5	0.2	0	0	0	0.2	3

Table 2 is a record of more than local convectional storms. The thunderstorms which occur from December to March are most probably connected with winter depressions. From March to September most of the thunderstorms for Karachi and Ormara are connected with Arabian Sea cyclones and eastern depressions. The higher number for Las Bela two in April, three in May, June, and August, and four in July — represent convectional storms of a typical interior station where moist air, carried inland from the Arabian Sea during the modified monsoon season, rises and forms cumulo-nimbus clouds and a typical convective system.

Thus, for much of Baluchistan a third reason for the lack of thunderstorms is the absence of a mechanism to lift the moist air and break through the subsidence inversion. Lower layers of air become very humid during the modified monsoon season and remain so until an outside depression invades the desert of southern Baluchistan. The convergency associated with such a depression lifts the moisture, which then produces sudden brief thundershowers. Possibly, stagnant humid pockets of air, moisture left at the end of the monsoon season, remain in desert basins until the arrival of western depressions in midwinter.

b) Reasons for the Occurrences of Dust Storms

Bare rock surface and areas of low elevation, such as dry river valleys and basins, are hotter than vegetated plains or surrounding hills, and differential heating produced local convection. Hot, dry, alluvial valleys provide an excellent source for wind-blown materials. Local winds associated with the convection are strong enough on a hot afternoon to pick up fine stilts and clays [30].

c) Frequency of Occurrence

Dust storms and sandstorms are frequent in the arid regions of West Pakistan, especially during the dry season from March to June, with local dust storms being most frequent in the afternoon. Larger dust storms associated with an approaching depression occur at any hour of the day and sometimes at night. The largest number of storms often occurs in the eastern part of the Baluchistan, with Karachi averaging seventeen per year. The number of storms decreases toward Iran. May has the largest number of dust storms because it is the hottest, driest month; however, the largest dust storms are associated with eastern depressions when easterly winds bring large amounts of dust off the Thar Desert. Coastal areas, such as the Las Bela coastal plain, have local dust storms nearly every day when there is a strong sea breeze.

5. Type 5: The Modified Monsoon Pattern

The monsoon system in southern West Pakistan is an extreme modification of the true monsoon pattern over India. Its main influence is felt in Sind, eastern Baluchistan and coastal Makran. Here a seasonal flow of air is based upon a difference in temperature between the very hot land and the cooler Arabian Sea. It is not a sufficiently well-developed system in southern and eastern Asia [31].

a) Physical Characteristics

During the winter season the sea breeze is local and has diurnal variation, blowing off the sea during the afternoon and off the land in the early hours of the morning. By March, however, the sea breeze becomes more pronounced and by June is submerged in the dominant southwest to west-southwest current, a modified monsoon system, which is fairly constant during the day and night. When the sea breeze exceeds the Beaufort Scale of 3 m. p. h. (4.8 km per hour) it is said to be a monsoon wind. The flow of air is best developed from the latter part of June through July and August. In July the wind reaches a speed of 20 m. p. h. (32.2 km per hour) and penetrates up to 200 miles (321.9 km) inland from the coast [32].

Stratus and strato-cumulus clouds accompany this southwest current and begin to move across the coast about mid-June. Being 1500 to 2000 feet (457—609 m) high, they become thick enough to form a 7 to 8 tenths cloud cover during July and August [33]. In September the cloud concentration drops off to 5 or 6 tenths, and by October cloudless skies return. There is diurnal and nocturnal variation in cloud covers; they are thickest in the mornings and evenings while their base is lowest at night. Although they are not thick enough to develop into true rain clouds, the cloud covers do reduce temperatures during the monsoon season over eastern coastal areas. However, a 70 to 80 per cent relative humidity in the afternoon results in sultry conditions. At night or early morning, when the temperature drops to the dew point, a light drizzle will occur, but heavy showers are extremely rare [34 and 35]. Heavy rains occasionally occur when the I. T. C., located over the north Arabian Sea, moves north across the coast of southern Iran and West Pakistan. Under these conditions the stage is set for an eastern depression to enter the area.

b) Synoptic Characteristics

Much of southwest Asia, including southern Iran and Baluchistan, is dominated during June, July, and August by the large subtropical anticyclonic high pressure system which extends eastward as far as the border-lands of the Indus Valley. This single large high, an extension of the Azores High, is characterized by dry northerly, hot winds — the trade-like Etesians — diverging at higher elevations to produce a temperature layer over much of southern West Pakistan. The subsiding air forms a capping over the more humid monsoon air. In the areas along the Arabian Sea, surface humidity and surface heating are high. The hot upper winds prevent moisture laden convectional currents from rising. Near the coast the inversion layer is at an elevation or about 3000 feet (914 m) and inland it is seldom higher than 6000 feet (1828 m). This is hardly conducive to the development of towering cumulus clouds. A cross section of the capping action is depicted in Fig. 6 [36]. The inversion layer slopes; toward the east it is 3000 to 4000 feet (914 to 1219 m) near Karachi while to the west over Gwadar and Jask it is so close to the surface that only a weak sea breeze is able to form along with a few clouds. To the northeast it is higher, reaching 10 000 feet (3048 m) in the vicinity of Lahore [37].

6. Type 6: Eastern Depressions

The weak modified monsoon pattern over the desert of Sind and eastern Baluchistan is not normally conductive to heavy rainfall. One of two conditions must be present: it takes either a vigorous

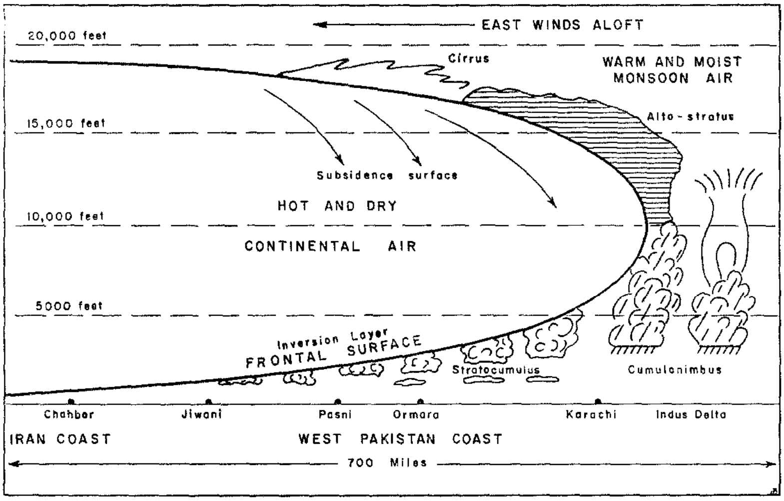

Fig. 6. Modified Monsoon Pattern over Sind and Baluchistan during June, July, and August (adapted from J. S. Sawyer [36])

storm pattern from the main monsoon system of India to push back and break the dominance of the subtropical anticyclonic pressure system or a retreat of the anti-cyclone itself which then permits a storm to enter the area.

a) Physical Characteristics

Most of the eastern depressions reaching southern West Pakistan have a Beaufort force of 7 or less and are not cyclones for unless a storm has strong gusts it is not considered a tropical cyclone [32]. The eastern depressions, the dying stages of a cell of low pressure which has travelled many miles across central India and the Thar Desert, may trigger occasional passing showers and squally overcast weather along with dust storms and rough seas along the coast; but, unless joined by an Arabian Sea depression, they seldom result in long periods of rain.

Because of the eastern depressions, July is the wettest month for the Thar Desert, Sind and the eastern part of Baluchistan. Karachi has an average of two rain days in July, meaning that on the average two storms will reach the area. June and August each average one storm. Table 1, depicting the variability of rainfall for Karachi, indicates the erratic nature of precipitation [6].

Once every 10 to 20 years an eastern depression will bring large amounts of rain. As much as 8 in. (203 mm) of precipitation has fallen at Karachi in 24 hours as one squall followed another. Water collects in low places and local flooding can be serious after torrential showers. The summer of 1959 was an exceptionally wet year for eastern Baluchistan as shown by the data collected at the Sonmiani weather station (Table 3).

Table 3. *Rainfall at Sonmiani June through September 1959*[1]
(Rain amounts in inches ″ and mm)

June 31	0.14″	(3.6 mm)	
July 1	0.39″	(9.9 mm)	12.12 in. (30.8 mm) of precipitation fell in 5 days as a result of an eastern depression joining with an Arabian Sea cyclone over southern West Pakistan
July 3	5.07″	(128.8)	
July 4	5.22″	(132.6)	
July 15	0.80″	(20.3)	Small eastern depression
July 30	0.97″	(24.6)	Eastern depression (July 30–31)
July 31	0.14″	(3.6)	
August 15	0.33″	(8.4)	Eastern depression
September 5	0.14″	(10.4)	This was an unusial eastern depression because it occurred very late in the season and remained stationary for 14 days resulting in a total of 2.88 in. (73.2 mm) of rainfall for September (September 5–19)
September 7	0.70″	(17.8)	
September 11	0.17″	(4.3)	
September 12	0.41″	(10.4)	
September 16	0.51″	(12.9)	
September 17	0.88″	(22.4)	
September 18	0.32″	(8.1)	
September 19	0.11″	(2.8)	
Total	17.24″	(437.9)	

[1] Records from the weather station at Sonmiani, West Pakistan.

The following is a summary of an eastern depression which crossed over Sind and the eastern part of Baluchistan on July 15, 1959 (Fig. 7). On July 8, 1958, a depression was reported in the Bay of Bengal, and a small depression was plotted on the weather map over central India (Fig. 7 A). By the morning of July 13 this low pressure area had developed into a well-marked depression, and on July 14 it was classified as a typical eastern depression (Fig. 7 B). The storm passed over Bhug, India about midday on July 15 with winds up to gale force.

Since the storm at this time was partly over land and partly over the sea (Fig. 7 C), its exact path was difficult to follow. It broke up into a number of cells which moved on across Sind toward Karachi and the Baluchistan hills. Late in the afternoon of the 15th, Karachi had strong northeasterly winds, and a squall front passed over the city with lightning and thunder around 6 : 00 p. m., dropping 0.50 in. (13 mm) of rain in three hours. By 9 : 00 p. m. the storm had

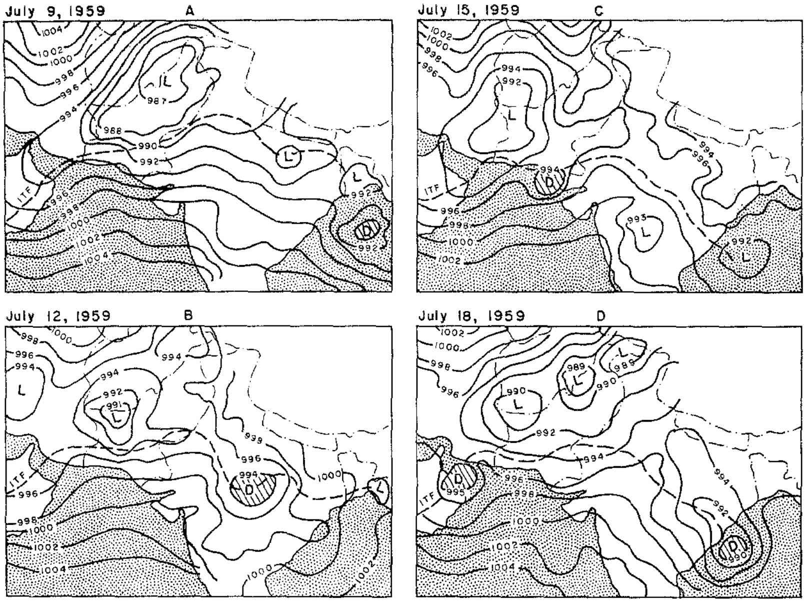

Fig. 7. Movement of an eastern depression from the Bay of Bengal across central India to southern west Pakistan and the Arabian Sea (Pakistan Daily Weather Maps, Pakistan Meteorological Department, Karachi)

passed, the sky began to clear, and no appreciable drop in temperature was noted. On July 16 the depression was 80 miles (128.7 km) south-southwest of Karachi moving westward along the Makran coast. It passed over Sonmiani where it dropped 0.80 in. (20 mm) of rain and no rain was recorded farther west. On the 18th of July it was reported in the Gulf of Oman (Fig. 7 D).

b) Synoptic Characteristics

Much of the monsoon rainfall over the Indian Subcontinent and Burma is associated with depressions that originate over the Bay of Bengal, the Arabian Sea, or occasionally over central India. Most of these storm cells move in a counterclockwise direction toward more northerly latitudes following a fluctuating I. T. C. [38]. However, one or two per year will move west across the Thar Desert of India and meet fresh moist monsoon air moving inland from the north Arabian Sea (Fig. 7). Reasons for only a few of the eastern depressions moving directly west or even south are complex and are not fully understood [36]. According to TREWARTHA [9] conditions are ripe for the movement of an eastern depression into the Sind area when an elongated trough of low pressure, actually part of the I. T. C., exist over central India and its eastern part extends as far as the Bay of Bengal.

The storm in mid-July 1959 followed such a course along the I. T. C. (Fig. 7). If the I. T. C. is migrating north or south, particularly in June or September, it will be located over Sind and eastern Baluchistan just as one of these depressions begins to move westward. The stage is thus set for a storm cell to follow a new path rather than the usual one toward the Punjab. However, the paths of eastern depressions are difficult to follow because the storms are very erratic. Often a dying depression over central India becomes stationary, but quite suddenly reforms over the Thar Desert, and with the influx of fresh monsoon air from the Arabian Sea, moves rapidly westward over Sind and Baluchistan (Fig. 7).

Most of the eastern depressions reaching southern West Pakistan dissipate against the hill ranges and rarely reach as far west as Iran or Iraq. This westward extension, however, can occur when the storm crosses Sind and moves out across the north Arabian Sea along the Makran coast. Such a storm will often pick up moisture and bring heavy rain, rough seas, and squally weather as far west as Gwadar and the Gulf of Oman and has been known to cause thunderstorms over the hilly sections of Oman west of Muscat [30]. For a storm pattern to reach this far west depends upon the location of the I. T. C. over the north Arabian Sea. The I. T. C. may provide the steering effect for an eastern depression to follow and also helps to displace the dry, stable anticyclonic system which dominates the upper air of southwest Asia. The storms which move along the Makran coast skirt the southern fringe of this high pressure system [40].

The above is one postulated situation in which a storm cell does not follow the normal flow of monsoon air. Other conditions under which normal flow is altered occur when an upper air high pressure ridge over northern India steers eastern depressions from the Punjab or, on rare occasions, when an Arabian Sea low pressure cell draws an eastern depression farther south than is usual. More study needs to be made of easterly wave disturbances from Burma and the role of jet streams in influenceing the movement of storm cells [20, 41]. Recent satellite pictures are revealing some interesting patterns [42].

Any storm pattern which reaches Sind and southern Baluchistan and infrequently Iran, is the result of breakdown or change in the normal monsoon circulation.

V. Synopsis of Weather Patterns

Tables 4 and 5 correlate the seasons of the year to the six patterns of weather predominant in the eastern and western parts of southern West Pakistan. Farther east in India and farther west in

Table 4
Types and Patterns of Weather Reaching the Eastern Part of Southern Baluchistan

Type	Transition Season (Sept. to Oct.)	Winter Season (Nov. to March)	Hot Season (April to June)	Monsoon Season (July and August)
1 Subtropical Anticyclonic Pattern	Most Predominant Weather Pattern ←———	———	————	Still Persists but not as low in Elevation ·····→ Inversion Layer
2 Winter Cyclonic Pattern	Occasionally Occurs ←·····	Most Frequent ←———→ 3—4 storms per year	Occasionally Occurs ·····→	
3 Arabian Sea Cyclones	Occasionally ←·····→ Reach the coast		Most Frequent ←———→ 1 storm in 3 years	
4 Local Storms	Occasionally Occur ←·····	·····	Most Frequent ····· 5—6 storms per year	Occasionally Occur ·····→
5 Modified Monsoon Pattern	Sometimes last ←·····→ to Mid-September		Sometimes Begins ←····· in Mid-June	Dominant Pattern ———→ Cloudiness and a little drizzle
6 Eastern Depressions	Occasionally Occur ←·····→ to Mid-September		Occasionally ←····· Come in Mid-June	Most Frequent ———→ 3—4 storms per year

Iran the pattern changes. To the east the modified monsoon is a more developed system and eastern depressions bring heavier rainfall. Winter cyclonic storms are almost non-existent. However, on the west side of Baluchistan in Iran it is just the opposite. The winter cyclonic storms are the most influential and the summer monsoon eastern depressions are rare (Fig. 2 and Table 6). The sub-

Table 5. *Types and Patterns of Weather Reaching the Western Part of Southern Most Pakistan*

Type	Transition Season (Sept. to Oct.)	Winter Season (Nov. to March)	Hot Season (April to June)	Monsoon Season (July and August)
1 Subtropical Anticyclonic Pattern	Most Predominant Weather Pattern			Well Developed
2 Winter Cyclonic Pattern	Occasionally Occurs	Most Frequent 4—5 storms per year	Occasionally Occurs	
3 Arabian Sea Cyclones	Rarely Occur		Occasionally Reach the Coast	
4 Local Storms	Occasional Dust Storm		Occasional Dust Storm and Squall	
5 Modified Monsoon Pattern				Not a Well Developed System
6 Eastern Depressions				Very Rarely Reach the Coast

tropical anticyclonic system (Type 1) is the dominant type of weather pattern for all of southwest Asia. It is never entirely absent from

Table 6. *Type and Number of Storms Reaching the Makran Coast of West Pakistan and Iran*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Karachi: (Drigh Road) July 28 to December 1935 (Rao, [4]) (Eastern Side of the Makran Coast, West Pakistan)													
Number of Storms	0.4	0.1	0.7	0.3	0.9	1.1	1.7	0.1	0.6	0.3	0.3	0.0	6.5
Storm Type	2	2	2.4	4	3—4	3—6	6	6	3—6	3—4	2		
Jask, Iran 28 year period (Ganji [40]) (Wester Side of the Makran Coast, Iran)													
Number of Storms	2.3	1.8	1.4	0.4	0.0	0.1	0.0	0.0	0.0	0.3	0.4	2.3	9.0
Storm Type	2	2	2	2—3—4		3—4				2—3	2	2	

Numbers indicate the following storm types: 2 = Winter Cyclonic Depressions, 3 = Arabian Sea Cyclones, 4 = Local Storms (Dust Storms and Thunderstorms), 6 = Eastern Monsoon Depressions.

southern West Pakistan but will occasionally be displaced by active disturbances, especially Arabian Sea cyclones and monsoon eastern depressions. During the monsoon season, July and August, over the eastern part of the region it is a strong upper air pattern with a pronounced inversion layer. For the interior part of Baluchistan and Sind the anticyclonic pattern is the prevailing weather type for 90 per cent of the year.

Type 2, the winter cyclonic storm pattern, will occasionally begin as early as October and continue sporadically into April, but the storms are most frequent from November to March with an average of three to five storms per year crossing southern West Pakistan. Arabian Sea cyclones, Types 3, occasionally occur in the transition season of September and October, but are more frequent in the hot season when on the average one severe storm in 3 years will reach the coast of West Pakistan and Iran. Local storms, thunderstorms and dust storms can occur any season of the year but are most frequent during the hot season when great surface heating takes place. Some years the modified monsoon pattern, which is best developed in July and August over eastern Baluchistan, begins in mid-May and lasts until mid-September and is characterized by strong southwest winds and thick layers of strato-cumulus clouds. Eastern depressions, numbering three or four per year, are most frequent in July and August but occasionally begin in mid-June and extend into September. These storms normally penetrate the eastern part of Baluchistan and, as Table 5 indicates, rarely reach the western part of the coast.

Table 6 summarizes the average number and type of storms per year which reach the southern part of West Pakistan and Iran. The figures for Karachi show the average number of storms per year recorded at the Drigh Road station from July 1928 to December 1935 [4]. The figures for Jask, Iran give the average number of storms reaching the western part of the Makran coast over a 28 year period [37]. A comparison of these two areas clearly shows that while southern West Pakistan receives a few winter cyclonic storms — mainly in January, February and March — southern Iran has about seven of its total nine storms per year from this one storm type. In comparison, for a 7-year period at Karachi not a single storm occurred in December. On the other hand, except for an occasional Arabian Sea cyclone and a local dust storm or thunderstorm, southern Iran received no major storms from May until October during the 28 year period.

The prevailing wind directions for the different weather types are roughly indicated in Table 7. Winds during the anticyclonic pattern are most prevalent from the west; but, as high pressure cells pass nearby, the wind shifts to the northeast, north, or northwest depending upon location of the cell. During a winter cyclonic storm the wind will often shift from southeast to southwest to north-

Table 7. *Prevailing Wind Directions for the Different Weather Types*

Northerly	Anticyclonic Pattern-land breeze dry and cold in winter, hot in summer (33 days)
Northeasterly	Anticyclonic pattern in winter — A landbreeze curing hot season produces local dust storms — Monsoon season indicates an eastern depression — potential rain bearing wind (69 days)
Easterly	(16 days)
Southeasterly	(4 days) These directions are of rare occurrence. They occur during squalls and thus usually indicate adverse weather.
Southerly	(3 days)
Southwesterly	Modified monsoon pattern (sea breeze) — moist wind and low clouds (50 days)
Westerly	Anticyclonic pattern — most prevalent wind of southern Baluchaistan — Fair weather (130 days)
Northwesterly	This wind follows a winter cyclone. During hot season and transition season, mostly April and October, brings not air off desert, dust haze (35 days)
Calm	An average of 25 days per year are calm in which the wind force is less than one mile per hour. Calm weather experienced mostly in December when in some years as many as 25 days out of the month have no wind. Other months in which the wind frequently becomes calm are October, November and May. In June and July there are no completely calm days.

west as a veering wind does around a cyclonic storm in the middle latitudes. A local thunderstorm or dust storm will also have winds from several directions. The most uniform and strongest wind comes during the modified monsoon pattern from mid-June to mid-September. During the monsoon season a northeast wind off the Thar Desert usually means a disturbance is nearby, but when the eastern depression passes over, the squalls will have winds from several directions.

VI. Conclusions

Southern West Pakistan, located in a transition zone between the summer monsoon circulation to the east and the winter cyclonic pattern to the west, receives only the last dying effects of both. It is remarkable that any moisture reaches this area since subtropical, anticyclonic, subsiding air is not conducive to the upward movement and resulting condensation of moisture. Most of the year the influence of this high pressure capping extends well out over the Arabian Sea preventing moisture from reaching the coast. The moisture which does flow into southern West Pakistan during the modified monsoon season is confined below 5000 feet (1524 m) by a very well-developed inversion layer.

Winter cyclonic disturbances, monsoon eastern depressions, Arabian Sea cyclones, and local convectional thunderstorms are the four storm patterns occurring in the breaks between the anticyclonic pattern and are capable of triggering condensation.

The winter cyclonic disturbances moving across southwest Asia are in a dying stage by the time they reach southern Baluchistan. Often they are feeble secondary depressions which become fragmented into a series of cells and are generally unreliable storms which bring overcast days and little precipitation. Exceptions to this pattern result if the cells cross the north Arabian Sea, picking up moisture or if they underride stagnant moist air in pocket basins.

The eastern depressions, which cross India during the monsoon season, bring rain to the Thar Desert and Sind but are often too weak to penetrate far west. Most of these quickly dissipate once they reach the hills of Baluchistan.

Arabian Sea cyclones are the most potentially dangerous storms to reach southern West Pakistan. However, they mainly affect coastal regions, and because they directly affect only one section of the coast on the average of once in 3 years, they are an unreliable source of precipitation.

Very few storms originate within the area; even the fourth storm pattern, local thunderstorms and dust storms, may be indirectly triggered by feeble disturbances that originated miles away. Although the number of disturbances reaching this region may be few, the intensity of some of the storms is amazing. Torrential downpours can occur within a few hours, and sometimes a depression will remain over an area for several days producing one heavy squall after another. Once a break or displacement in the anticyclonic pressure system exists and an active storm pattern with sufficient moisture is near, cyclogenesis can take place and nature can go on a rampage.

Acknowledgements

The author is highly indebted to Mr. S. N. NAQVI, former director of the Pakistan Meteorological Department, and Mr. A. K. SHERWANI, Assistant Meteorologist in the same department, for their help in compiling the data. I am also indebted to Dr. R. A. BRYSON at the University of Wisconsin and Drs. RICHARD J. RUSSEL and HARLEY J. WALKER at Louisiana State University for their critical reading of the paper. Field work for this study was sponsored by Coastal Studies Institute, Louisiana State University, under auspices of the Geography Branch, Office of Naval Research, Contract No. Nonr. 1575 (03), Task Order No. NR 388 002, during the summer and fall of 1959 and 1960. The paper was compiled at Clark University under the auspices of the Geography Branch, Office of Naval Research, Contract No. N000 14-66-C0104, Project No. Nr 388 082.

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