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# Monsoon Season: Nature's Dynamic Blessing

The monsoon season is a pivotal natural phenomenon that profoundly impacts climates, ecosystems, economies, and societies across vast regions of the world. From Asia to Africa and the Americas, the arrival of the monsoon brings relief from scorching heat, replenishes agricultural lands, sustains biodiversity, and shapes cultural practices. This essay explores the monsoon season in depth, examining its mechanisms, impacts, challenges, and cultural significance.



and songs reflect communities' intimate connection with nature's rhythms. Indian monsoon, the most prominent of the world's monsoon systems, which primarily affects India and its surrounding water bodies. It blows from the northeast during cooler months and reverses direction to blow from the southwest during the warmest months of the year. This process brings large amounts of rainfall to the region during June and July.

At the Equator the area near India is unique in that dominant or frequent westerly winds occur at the surface almost constantly throughout the year; the surface easterlies reach only to latitudes near 20° N in February; and even then they have a very strong northerly component. They soon retreat northward, and drastic changes take place in the upper-air circulation (see climate: Jet streams). This is a time of transition between the end of one monsoon and the beginning of the next. Late in March the high-sun season reaches the Equator and moves farther north. With it go atmospheric instability; convectional (that is, rising and turbulent) clouds, and rain. The westerly subtropical jet stream still controls the flow of air across northern India, and the surface winds are northeasterlies.

**Monsoon onset and early developments**

Map of climatic heat sources and heat sinks for Asian summer and winter monsoons.

As the high-sun season (that is, the Northern Hemisphere summer) moves northward during April, India becomes particularly prone to rapid heating because the highlands to the north protect it from any incursions of cold air. There are three distinct areas of relative upper tropospheric warmth—namely, (1) above the southern Bay of Bengal, (2) above the Plateau of Tibet, and (3) across the trunks of the various peninsulas that are relatively dry during this time. These three areas combine to form a vast heat-source region. The relatively warm area above the southern Bay of Bengal occurs mostly at the 500-100-millibar level. (This atmospheric pressure region typically occurs at elevations between 5,500 and 16,100 metres [18,000 and 53,000 feet] but may vary according to changes in heating and cooling.) It does not appear at a lower level and is probably caused by the release of condensation heat (associated with the change from water vapour to liquid water) at the top of towering cumulonimbus clouds along the advancing intertropical convergence. In contrast, a heat sink appears over the southern Indian Ocean as the relatively cloud-free air cools by emitting long-wavelength radiation. Monsoon winds at the surface blow from heat sink to heat source. As a result, by May the southwest monsoon is well-established over Sri Lanka, an island off the southeastern tip of the Indian peninsula.

Also in May, the dry surface of Tibet (above 4,000 metres [13,100 feet]) absorbs and radiates heat that is readily transmitted to the air immediately above. At about 6,000 metres (19,700 feet) an anticyclonic cell arises, causing a strong easterly flow in the upper troposphere above northern India. The subtropical jet stream suddenly changes its course to the north of the anticyclonic ridge and the highlands, though it may occasionally reappear southward of them for very brief periods. This change of the upper tropospheric circulation above northern India from westerly jet to easterly flow coincides with a reversal of the vertical temperature and pressure gradients between 600 and 300 millibars. On many occasions the easterly wind aloft assumes jet force. It anticipates by a few days the "burst," or onset, of the surface southwesterly monsoon some 1,500 km (900 miles) farther south, with a definite sequential relationship, although the exact cause is not known. Because of India's inverted triangular shape, the land is heated progressively as the sun moves northward. This accelerated spread of heating, combined with the general direction of heat being transported by winds, results in a greater initial monsoonal activity over the Arabian Sea (at late springtime), where a real frontal situation often occurs, than over the Bay of Bengal. The relative humidity of coastal districts in the Indian region rises above 70 percent, and some rain occurs. Above the heated land, the air below 1,500 metres (5,000 feet) becomes unstable, but it is held down by the overriding easterly flow. This does not prevent frequent thunderstorms from occurring in late May.

**Peak period**

During June the easterly jet becomes firmly established at 150 to 100 millibars, an atmospheric pressure region typically occurring at elevations between 13,700 and 16,100 metres (45,000 and 53,000 feet). It reaches its greatest speed at its normal position to the south of the anticyclonic ridge, at about 15° N from China through India. In Arabia it decelerates and descends to the middle troposphere (3,000 metres [9,800 feet]). A stratospheric belt of very cold air, analogous to the one normally found above the intertropical convergence near the Equator, occurs above the anticyclonic ridge, across southern Asia at 30°-40° N and above the 500-millibar level (6,000 metres [19,700 feet]). These upper-air features that arise so far away from the Equator are associated with the surface monsoon and are absent when there is no monsoonal flow. The position of the easterly jet controls the location of monsoonal rains, which occur ahead and to the left of the strongest winds and also behind them and to the right. The surface flow, however, is a strong, southwesterly, humid, and unstable wind that brings humidities of more than 80 percent and heavy squally showers that are the "burst" of the monsoon. The overall pattern of the advance follows a frontal alignment, but local episodes may differ considerably. The amount of rain is variable from year to year and place to place.

Most spectacular clouds and rain occur against the Western Ghats in India, where the early monsoonal airstream piles up against the steep slopes, then recedes, and piles up again to a greater height. Each time it pushes thicker clouds upward until wind and clouds roll over the barrier and, after a few brief spells of absorption by the dry inland air, cascade toward the interior. The windward slopes receive 2,000 to 5,000 mm (80 to 200 inches) of rain in the monsoon season.

Various factors, especially topography, combine to make up a complex regional pattern. Oceanic air flowing toward India below 6,000 metres (19,700 feet) is deflected in accordance with the Coriolis effect. The converging moist oncoming stream becomes unstable over the hot land and is subject to rapid convection. Towering cumulonimbus clouds rise thousands of metres, producing violent thunderstorms and releasing latent heat in the surrounding air. As a result, the upper tropospheric warm belt migrates northwestward from the ocean to the land. The main body of air above 9,000 metres (29,500 feet) maintains a strong easterly flow.

Later, in June and July, the monsoon is strong and well-established to a height of 6,000 metres (less in the far north), with occasional thickening to 9,000 metres. Weather conditions are cloudy, warm, and moist all over India. Rainfall varies between 400 and 500 mm (16 and 20 inches), but topography introduces some extraordinary differences. On the southern slopes of the Khasi Hills at only 1,300 metres (4,300 feet), where the moist airstreams are lifted and overturned, the village of Cherrapunji in Meghalaya state receives an average rainfall of 2,730 mm (107 inches) in July, with record totals of 897 mm (35 inches) in 24 hours in July 1915, more than 9,000 mm (354 inches) in July 1861, and 16,305 mm (642 inches) in the monsoon season of 1899. Over the Ganges valley the monsoon, deflected by the Himalayan barrier, becomes a southeasterly airflow. By then the upper tropospheric belt of warmth from condensation has moved above northern India, with an oblique bias. The lowest pressures prevail at

the surface. It is mainly in July and August that waves of low pressure appear in the body of monsoonal air. Fully developed depressions appear once or twice per month. They travel from east to west more or less concurrently with high-level easterly waves and bursts of speed from the easterly jet, causing a local strengthening of the low-level monsoonal flow. The rainfall consequently increases and is much more evenly distributed than it was in June. Some of the deeper depressions become tropical cyclones before they reach the land, and these bring torrential rains and disastrous floods.

A totally different development arises when the easterly jet moves farther north than usual. The monsoonal wind rising over the southern slopes of the Himalayas brings heavy rains and local floods. The weather over the central and southern districts, however, becomes suddenly drier and remains so for as long as the abnormal shift lasts. The opposite shift is also possible, with midlatitude upper air flowing along the south face of the Himalayas and bringing drought to the northern districts. Such dry spells are known as "breaks" of the monsoon. Those affecting the south of India are similar to those experienced on the Guinea Coast during extreme northward shifts of the wind belts (see West African monsoon), whereas those affecting the north are due to an interaction of the middle and low latitudes. The southwest monsoon over the lower Indus plain is only 500 metres (about 1,600 feet) thick and does not hold enough moisture to bring rain. On the other hand, the upper tropospheric easterlies become stronger and constitute a true easterly jet stream. Western Pakistan, Iran, and Arabia remain dry (probably because of the divergence in this jet) and thus become the new source of surface heat.

**Monsoon withdrawal**

By August the intensity and duration of sunshine have decreased, temperatures begin to fall, and the surge of southwesterly air diminishes spasmodically almost to a standstill in the northwest. Cherrapunji still receives over 2,000 mm (79 inches) of rainfall at this time, however. In September, dry, cool, northerly air begins to circle the west side of the highlands and spread over northwestern India. The easterly jet weakens, and the upper tropospheric easterlies move much farther south. Because the moist southwesterlies at lower levels are much weaker and variable, they are soon pushed back. The rainfall becomes extremely variable over most of the region, but showers are still frequent in the southeastern areas and over the Bay of Bengal. By early October, variable winds are very frequent everywhere. At the end of the month, the entire Indian region is covered by northerly air and the winter monsoon takes shape. The surface flow is deflected by the Coriolis force and becomes a northeasterly flow. This causes an October-December rainy season for the extreme southeast of the Deccan (including the Madras coast) and eastern Sri Lanka, which cannot be explained by topography alone because it extends well out over the sea. Tropical depressions and cyclones are important contributing factors.

Workers transplanting rice near Mangalore, Karnataka, India. Agriculture on the Indian subcontinent frequently depends on summer monsoon rainfall because precipitation during other seasons may be sparse.

Most of India thus begins a sunny, dry, and dusty season. The driest period comes in November in the Punjab; December in central India, Bengal, and Assam; January in the northern Deccan; and February in the southern Deccan. Conversely, the western slopes of the Karakoram Range and Himalayas are then reached by the midlatitude frontal depressions that come from the Atlantic and the Mediterranean. The winter rains they receive, moderate as they are, place them clearly outside the monsoonal realm.

Because crops and water supplies depend entirely on monsoonal rains, it became imperative that quantitative long-range weather forecasts be available. Embedded in the weather patterns of other parts of the world are clues to the summer conditions in South Asia. These clues often appear in the months leading up to monsoon onset. For a forecast to be released at the beginning of June, South American pressure and Indian upper-wind data for the month of April are examined. These data, though widely separated from one another, are positively correlated and may be used as predictors of June conditions. Forecasts may be further refined in May by comparing rainfall patterns in both Zimbabwe and Java with the easterly winds above the city of Kolkata (Calcutta) in West Bengal state. In this situation the correlation between rainfall and easterly winds is negative.

