Frequently Asked Questions

FAQ 14.1 | How is Climate Change Affecting Monsoons?

Monsoons are the most important mode of seasonal climate variation in the tropics, and are responsible for a large fraction of the annual rainfall in many regions. Their strength and timing is related to atmospheric moisture content, land–sea temperature contrast, land cover and use, atmospheric aerosol loadings and other factors. Overall, monsoonal rainfall is projected to become more intense in future, and to affect larger areas, because atmospheric moisture content increases with temperature. However, the localized effects of climate change on regional *monsoon strength and variability are complex and more uncertain.*

Monsoon rains fall over all tropical continents: Asia, Australia, the Americas and Africa. The monsoon circulation is driven by the difference in temperature between land and sea, which varies seasonally with the distribution of solar heating. The duration and amount of rainfall depends on the moisture content of the air, and on the configuration and strength of the atmospheric circulation. The regional distribution of land and ocean also plays a role, as does topography. For example, the Tibetan Plateau—through variations in its snow cover and surface heating—modulates the strength of the complex Asian monsoon systems. Where moist on-shore winds rise over mountains, as they do in southwest India, monsoon rainfall is intensified. On the lee side of such mountains, it lessens.

Since the late 1970s, the East Asian summer monsoon has been weakening and not extending as far north as it used to in earlier times , as a result of changes in the atmospheric circulation. That in turn has led to increasing drought in northern China, but floods in the Yangtze River Valley farther south. In contrast, the Indo-Australian and Western Pacific monsoon systems show no coherent trends since the mid-20th century, but are strongly modulated by the El Niño-Southern Oscillation (ENSO). Similarly, changes observed in the South American monsoon system over the last few decades are strongly related to ENSO variability. Evidence of trends in the North American monsoon system is limited, but a tendency towards heavier rainfalls on the northern side of the main monsoon region has been observed. No systematic long-term trends have been observed in the behaviour of the Indian or the African monsoons.

The land surface warms more rapidly than the ocean surface, so that surface temperature contrast is increasing in most regions. The tropical atmospheric overturning circulation, however, slows down on average as the climate warms due to energy balance constraints in the tropical atmosphere. These changes in the atmospheric circulation lead to regional changes in monsoon intensity, area and timing. There are a number of other effects as to how

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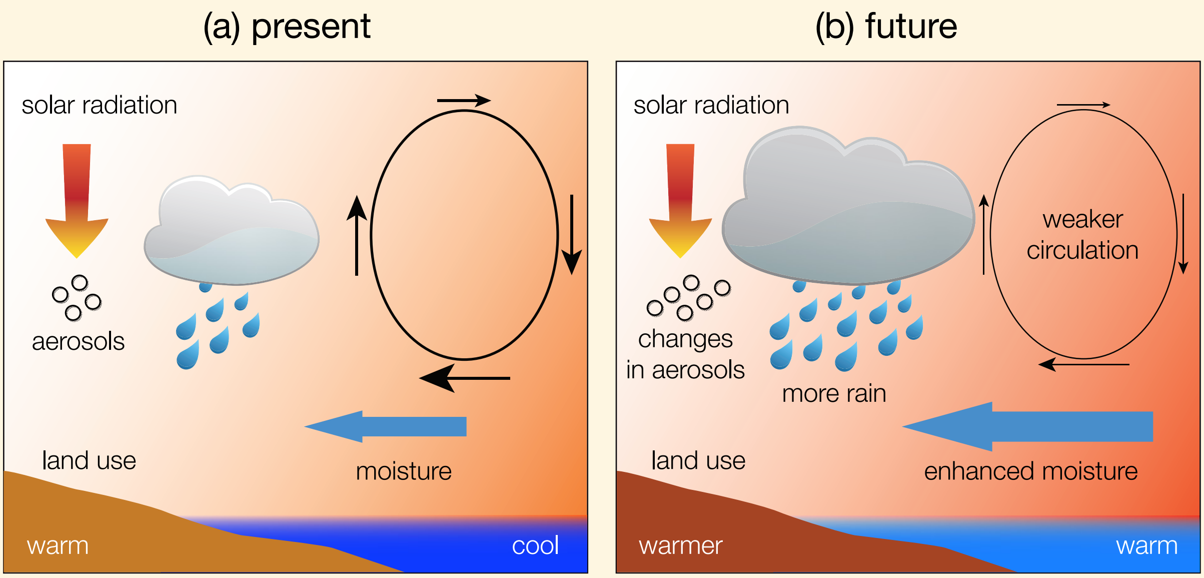

FAQ 14.1, Figure 1 | Schematic diagram illustrating the main ways that human activity influences monsoon rainfall. As the climate warms, increasing water vapour transport from the ocean into land increases because warmer air contains more water vapour. This also increases the potential for heavy rainfalls. Warming-related changes in large-scale circulation influence the strength and extent of the overall monsoon circulation. Land use change and atmospheric aerosol loading can also affect the amount of solar radiation that is absorbed in the atmosphere and land, potentially moderating the land–sea temperature difference.

FAQ 14.1 (continued)

climate change can influence monsoons. Surface heating varies with the intensity of solar radiation absorption, which is itself affected by any land use changes that alter the reflectivity (albedo) of the land surface. Also, changing atmospheric aerosol loadings, such as air pollution, affect how much solar radiation reaches the ground, which can change the monsoon circulation by altering summer solar heating of the land surface. Absorption of solar radiation by aerosols, on the other hand, warms the atmosphere, changing the atmospheric heating distribution.

The strongest effect of climate change on the monsoons is the increase in atmospheric moisture associated with warming of the atmosphere, resulting in an increase in total monsoon rainfall even if the strength of the monsoon circulation weakens or does not change.

Climate model projections through the 21st century show an increase in total monsoon rainfall, largely due to increasing atmospheric moisture content. The total surface area affected by the monsoons is projected to increase, along with the general poleward expansion of the tropical regions. Climate models project from 5% to an approximately 15% increase of global monsoon rainfall depending on scenarios. Though total tropical monsoon rainfall increases, some areas will receive less monsoon rainfall, due to weakening tropical wind circulations. Monsoon onset dates are *likely* to be early or not to change much and the monsoon retreat dates are *likely* to delay, resulting in lengthening of the monsoon season.

Future regional trends in monsoon intensity and timing remain uncertain in many parts of the world. Year-to-year variations in the monsoons in many tropical regions are affected by ENSO. How ENSO will change in future—and how its effects on monsoon will change—also remain uncertain. However, the projected overall increase in monsoon rainfall indicates a corresponding increase in the risk of extreme rain events in most regions.

Turner, 2012; Bollasina and Ming, 2013), poor skill in simulating the Madden–Julian Oscillation (MJO; Section 9.1.3.3) and uncertainties in projected ENSO changes (Collins et al., 2010; Section 14.4) and in the representation of aerosol effects (Section 9.4.6).

14.2.2.1 Indian Monsoon

The Indian summer monsoon is known to have undergone abrupt shifts in the past millennium, giving rise to prolonged and intense droughts (Meehl and Hu, 2006; Sinha et al., 2011; see also Chapter 2). The observed recent weakening tendency in seasonal rainfall and the regional re-distribution has been partially attributed to factors such as changes in black carbon and/or sulphate aerosols (Chung and Ramanathan, 2006; Lau et al., 2008; Bollasina et al., 2011), land use (Niyogi et al., 2010; see also Chapter 10) and SSTs (Annamalai et al., 2013). An increase in extreme rainfall events occurred at the expense of weaker rainfall events (Goswami et al., 2006) over the central Indian region, and in many other areas (Krishnamurthy et al., 2009). With a declining number of monsoon depressions (Krishnamurthy and Ajayamohan, 2010), the upward trend in extreme rainfall events may be due to enhanced moisture content (Goswami et al., 2006) or warmer SSTs in the tropical Indian Ocean (Rajeevan et al., 2008).

CMIP3 projections show suppressed rainfall over the equatorial Indian Ocean (Cai et al., 2011e; Turner and Annamalai, 2012), and an increase in seasonal mean rainfall over India (Ueda et al., 2006; Annamalai

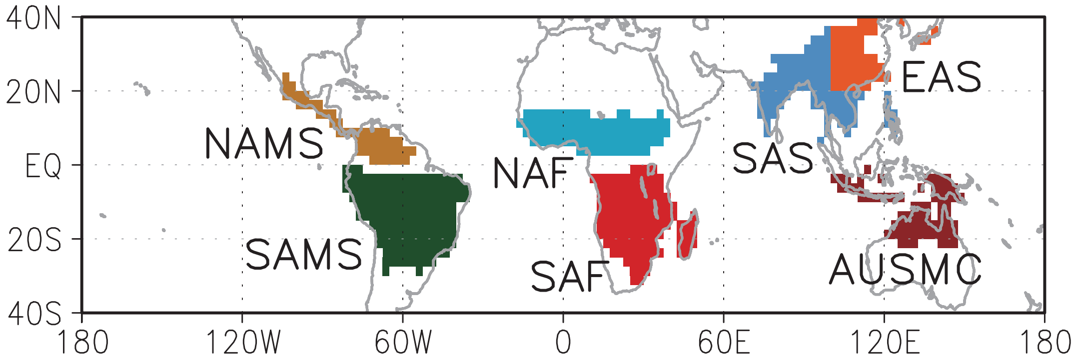

Figure 14.3 | Regional land monsoon domain based on 26 CMIP5 multi-model mean precipitation with a common 2.5° × 2.5° grid in the present-day (1986–2005). For regional divisions, the equator separates the northern monsoon domains (North America Monsoon System (NAMS), North Africa (NAF), Southern Asia (SAS) and East Asian summer (EAS)) from the southern monsoon domains (South America Monsoon System (SAMS), South Africa (SAF), and Australian-Maritime Continent (AUSMC)), 60°E separates NAF from SAS, and 20°N and 100°E separates SAS from EAS. All the regional domains are within 40°S to 40°N.