

### 3.2 Asian Eocene atmospheric circulation

EOC4X seasonal atmospheric circulation patterns are presented for winter (December-January-February) (Figure 4-a) and summer (June-July-August) (Figure 4-c) and compared to their modern counterparts (Figure 4-b,d). The winter circulation is characterized by a strong high-pressure belt at latitudes lower than today, located over the proto Himalayan Tibetan Plateau between 20 and 45°N. Strong westerlies are simulated at mid-latitudes around 40-50°N and easterlies at latitudes lower than 20°N (up to 15 m/s against 5 m/s in the Control simulation). These features contrast with the modern winter system characterized by zonal winds with a lower intensity and a larger meridional component. Finally, no analogue to the modern Siberian High is simulated at 40 Ma (Figure 4-b). Today, the Siberian High is controlled by winter surface temperatures dropping below the freezing point in northeastern Siberia (around 50°N). In our Eocene simulation, the combined effect of a warmer climate and a reduced continentality (due to the presence of the Paratethys and Siberian seas) prevent its development.

*During summer months, the nearby presence of the Tethys ocean and Paratethys sea results in a large high-pressure cell centered over 30°E and extending from 10° to 50°N (Figure 4-c). The Tethysian high is associated with intense 850 mb northerlies around 60°E which are partly deviated into northwesterlies when sweeping over northern Greater India (Figure 4-c). To the south, 850 mb winds originated from the Indian Ocean enter the Indian subcontinent at low latitudes (<10°N) and turn southeasterlies over the Bengal Bay to feed precipitations over the foothills of Himalaya before shifting to southwesterlies (Figure 4-c). In the modern configuration, the 850 mb winds of the SAM originate from the Indian Ocean and extend northward up to 20°N over India before taking a northeast direction and generate heavy precipitations from India to Myanmar and up to the southern flank of the Himalayas to the North (Figure 4-d, Figure 5-d). These precipitations over southern Asia (up to 15 mm/day, Figure 5-d) are fed by the Somali Jet, a strong low-level cross-equatorial moisture flow originating from the Indian Ocean which turns anticyclonically in the northern hemisphere along the eastern edge of the eastern African relief (Figure 4-d).*

*Figure 5 shows the equatorial moisture flow integrated over the whole atmosphere column for the Control and EOC4X experiments. In the Control Experiment, the largest meridional moisture transport crossing the Equator is simulated along the Eastern African coastline (Figure 5-b) and corresponds to the strongest meridional wind component. It confirms that the Somali Jet is a key feature of the modern Southern Asian Monsoon (Figure 5 b,d). Conversely in the EOC4X experiment, the Somali Jet (0-10°N/45-50°E) barely exists. Instead, moisture flows from the Tethys and Indian Oceans towards western Africa, where heavy summer precipitations are simulated (over 30 mm/day, Figure 5 c). This alternate moisture pathway toward western Africa rather than southern Asia is probably the result of several paleogeography features (African continent positioned farther south, absence of topography in eastern Africa, presence of a Tethysian seaway preventing the south Asian low pressure to extend westward) and will be discussed further in Section 4.2.*

*In western India, the cross-equatorial moisture flow is strongly reduced in EOC4X compared to the Control simulation, whereas it is increased over eastern India. However, this diverted equatorial moisture flux remains below 10°N and the Asian eastern Pacific coast receives instead a mixture of westerly winds coming from northern India (above 30°N) and weak easterly winds bringing moisture from the Pacific Ocean at lower latitudes (Figure 5-c), contrasting strongly with the modern EAM (Figure 5-d).*

These atmospheric changes, both in summer and winter, generate a large arid area extending throughout western China, the proto-Tibetan Plateau and northern India, while southern India and Myanmar experience intense rainfall due to their position closer to the equator in the Eocene (Figure 6-a,b). Apart from changes in near surface winds, two intertwined processes conspire to explain the aridity: (1) a rise in the water vapor condensation height (corresponding roughly to the cloud base) and (2) a weakly convective atmospheric column. The first process arises from the extreme surface air temperature in EOC4X (up to 45°C), which results in a simulated water condensation altitude that exceeds 3500 m over Northern India and Tibet. This altitude corresponds to a pressure level of ~680 mb (in the middle troposphere), while the water condensation altitude remains below 2500 m in the control experiment, which corresponds to a pressure level of ~800 mb (in the lower troposphere, Figure 6-c,d). The second process, the lack of deep convection, makes mid-level atmospheric layers very dry and prevents air masses to reach the water condensation altitude, as shown by two longitude-altitude cross sections of the relative humidity at 20°N and at 40°N (Figure 7).

At 20°N today, modern India and Southeast Asia show multiple deep convection centers and a relative humidity around 60% in most of the troposphere (Figure 7-d). In contrast, the Eocene displays a more stratified atmosphere, with two weak convective cells above the Indian and Southeastern Asian land masses, which are blocked around 600 mb by subsiding air masses. *Locations of deep convective heating can also be highlighted by observing the upper troposphere temperature maxima in the tropics (Boos and Kuang, 2010; Privé and Plumb, 2007; Roe et al., 2016), as presented in Figure 8. In the Control experiment, upper temperature maxima are located over northern India deep convection regions (Figure 8-b), which is in good agreement with reanalysis (see SI, Figure 6). Deep convection tends to occur where latent and sensible heats per unit mass maximize which is close to the subcloud surface (Emanuel et al., 1994), where temperature and relative humidity are elevated. In the control experiment, deep convection over India appears to be mostly controlled by latent heat because evaporation of precipitated water ensures moisture availability. Yet, in EOC4X, the latent heat over India is largely weaker due to a lack of moisture despite warmer temperatures. Consequently no upper-level temperature peak is simulated over northern India but rather over the Western Pacific (Figure 8-a), where both temperature and relative humidity are the highest.*

At 40°N, the presence of the Paratethys sea and the Tarim basin as far as 80°E is translated into a shallow surface of high relative humidity (~70%, see Figure 7-a), which is confined in the lowest troposphere levels by strong subsiding winds. The deep convection is here again muted by large-scale mid-level atmospheric dynamics. These diagnostics converge to demonstrate that our simulated Eocene atmosphere in Asia has little in common with the modern. The application of the Webster and Yang Index (WYI) (Webster and Yang, 1992) further confirms these atmospheric contrasts. The WYI is a standard diagnostic criterion for the SAM that quantifies the shear effect between the lower and higher troposphere, which is a typical characteristic of this monsoon. Modern WYI summer values over the northern Indian Ocean exceeds 20 whereas our EOC4X simulation yields summer values below 6 (Figure 9), thereby emphasizing the strong differences between Eocene and modern summer circulation patterns in this region.