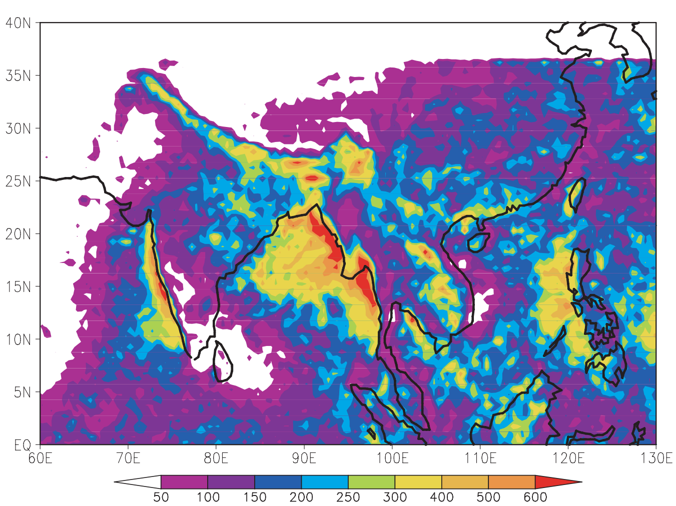
Narrow Mountains of Asia Shape Monsoon Circulation

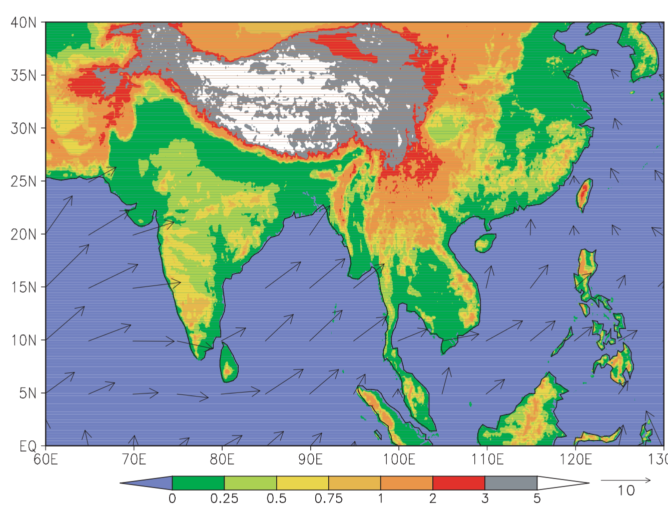
Imagine a world without mountains! Temperature, wind and rainfall patterns would differ greatly from what we know. In Asia, the very high Tibetan Plateau exerts a strong influence on climate. Heated directly by intense solar radiation during summertime, the temperatures in June–August form a regional maximum. Lhasa at 3.65 km above sea level, for example, has an average comfortable 15°C during summer, a far cry from the nearly freezing temperatures found at the same altitude and latitude a few thousand kilometers to the east over the North Pacific. The high-altitude heat source intensifies the summer monsoon of Asia and draws the monsoonal flow towards the plateau. The impact of the Tibetan Plateau on the summer monsoon circulation was recognized in the late 1950s and explicitly demonstrated by Syukuro Manabe and colleagues in the 1970s with a general circulation model of the atmosphere they developed at Princeton (see *IPRC Climate*, Vol. 5, No. 2).

While the effect of the massive Tibetan Plateau on the monsoon is now well known, the role of other, less massive mountains has not received much attention. IPRC team co-leader for Indo-Pacific climate **Shang-Ping Xie** and **Haiming Xu** and their colleagues at IPRC and NASA's Jet Propulsion Laboratory decided to study the role of these mountains in images from the first precipitation radar flown in space on the Tropical Rain Measuring Mission (TRMM) satellite. They noticed that, except for the rain band hugging the foothills of the Himalayas, all the major rain bands over South and Southeast Asia during summer are anchored on the windward side of mountain ranges (Figure 1).

Figure 1. June–August climatology of surface precipitation (mm/month) based on TRMM precipitation radar observations (**left panel**); land orography (km) and QuikSCAT surface wind velocity (m/s; **right panel**).



TRMM-PR Rainfall (mm/month; JJA)



Orography (km)

The rain band at the foot of the Himalayas is associated with the daily heating and cooling of the mountains. All the other rain bands form as the prevailing southwest monsoon impinges on the north-south oriented mountain ranges and the air is forced to rise. These mountain ranges are not much more than 200 km wide in most places and, as a whole, are not very high. They each anchor an intense rain band on their windward side.

The Western Ghats in India, for example, capture the rain on their windward side, the side facing the Arabian Sea. In the rain shadow of these mountains to the east, southeastern India is dry as savanna. Across the Bay of Bengal, however, rainforest flourishes with heavy rainfall on the coastal mountain slopes of Myanmar. Even more telling, during summer, the northern Bay of Bengal features the deepest convection on Earth; yet the eastern regions of the bay along the coast of Myanmar record more rainfall.

Orographic effects on rainfall are seen elsewhere, for instance in Hawai'i. The Hawai'i rainfall has little effect, however, on the large-scale circulation of the atmosphere because the strong trade wind inversion prevents the vertical development of convection. High surface temperatures and moisture over the vast Asian monsoon region, though, are conducive to atmospheric deep convection.

Could the heat released in the rain bands along these mountain ranges affect the large-scale circulation? Xie and his team tested this possibility. Using the IPRC regional atmospheric model, they placed narrow heat sources along the coast of Myanmar, over Vietnam, and off the western coast of the Philippines to mimic the TRMM rainfall observations, the mountains being too poorly resolved in the model to create significant rainfall. Comparing this simulation with an unperturbed run without the rain-band heating, they found that the latent heating of these rain bands induced a continental-scale cyclonic circulation in the lower atmosphere (Figure 2). Changes in convection occurred even in the Arabian Sea and Bay of Bengal, where no convection had been placed. Thus, these rather unimpressive mountains not only influence rainfall nearby but, in the model at least, they exert a far-reaching influence on the monsoon system by seeding convection, which then interacts with the large-scale circulation.

The findings have implications for understanding the large-scale organization of convection, a long-standing problem in tropical meteorology. In the tropics, circulation and convection are tightly coupled. Convection and precipitation are always found where wind converges in the lower troposphere.

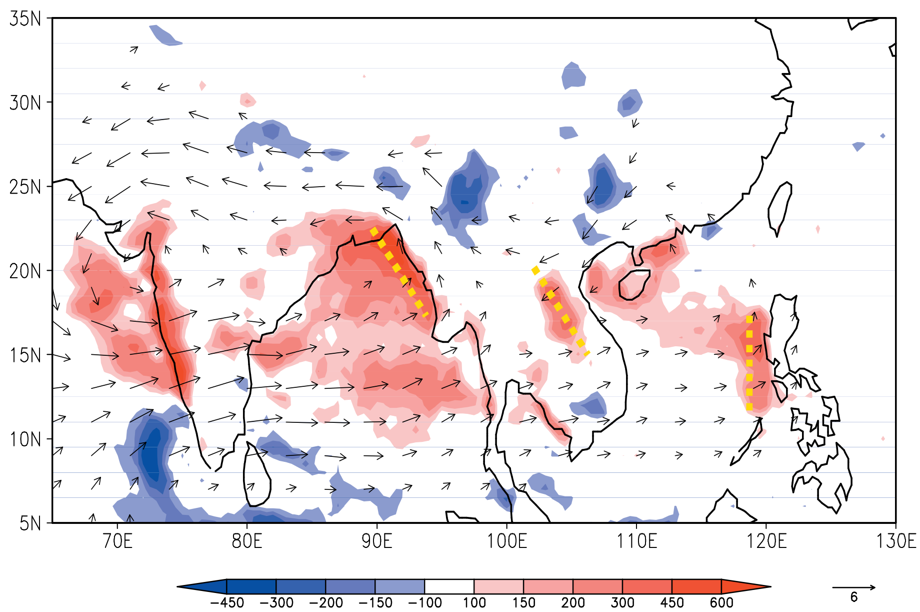


Figure 2. Model response to narrow heating bands (yellow dotted lines) that mimic orographic effects of mid-sized mountain ranges: differences in precipitation (color in mm/month) and 850h Pa wind vectors (m/s) between the simulation with heating bands and without. The wind vectors show the cyclonic circulation resulting from the release of latent heat in the rain bands.

This is a fundamental principle of tropical meteorology, but what causes what? Is a particular rainfall pattern induced by wind convergence or is it the other way around? This question is particularly acute in the study of the planetary disturbances of tropical convection, such as the important Madden-Julian Oscillation (see *IPRC Climate*, Vol. 4, No. 2, Data Surprises). Understanding the dynamics of this dominant tropical disturbance and simulating it in state-of-the-art numerical models remains a challenge. The IPRC study now shows that these rather modest mountain ranges, which have usually been not well resolved in general circulation models, block the path of the moisture-laden winds and short-circuit the interaction between convection and circulation. A conceptual model of the Asian monsoon therefore must include the mountain ranges.

The ability of general circulation models to simulate the orographic anchoring of monsoon convection is a critical test for the new-generation, high-resolution models. At the Frontier Research Center for Global Change in Yokohama, Japan, for instance, researchers are developing a super-high resolution global atmospheric model on Japan's supercomputer, the Earth Simulator. They have just completed a 3.5-km-resolution run of a hypothetical water-covered Earth and are now adding continents and mountains. This model will resolve mountains ranges of the size discussed here, and will, for the first time, explicitly simulate cloud clusters. These cloud clusters are tens to hundreds of kilometers in scale and an important building block for planetary-scale organization of tropical convection. Will this model be able to represent the rain bands in the Asian monsoon region that Xie and his colleagues have detected in the satellite images and that affect the large-scale atmospheric circulation?

The anchoring of rain bands by these mountains has also implications for scientists studying climates of the distant past. Asia was less mountainous before the Indian Plate collided with the Eurasian Plate. The tectonic building of the Tibetan Plateau has had a large impact on climate in Asia, the Indian Ocean, and beyond. The IPRC study means that the paleoclimate records must now take into account also the narrow mountain building and the rainfall patterns that they generate. The finding, furthermore, has implications for studying the interactions between wind, rainfall, and weathering, and how they shape the landscape of Asia, an upcoming line of research that cuts across meteorology, hydrology, and geology.

Above: View of the High Himalaya from the central Yarlang Valley in Tibet. (Courtesy of John Mahoney.) **Below:** Photo of rain clouds. (Courtesy of Axel Timmermann.)

Reference

Xie, S.-P., H. Xu, N.H. Saji, Y. Wang, and W.T. Liu, 2006: Role of narrow mountains in large-scale organization of Asian monsoon convection. *J. Climate*, in press (available at http://iprc.soest.hawaii.edu/~xie/meso-orog.pdf)

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