Patterns of Regional Climate Change



omprehensive global climate models predict that global average surface temperature will rise by about 1°C over the first 50 years of the present century if the global emissions of pollutants continue to grow in a "business as usual" economic and regulatory environment. Any practical effects of the anticipated climate change, however, will depend on the geographical distribution of the warming and other associated changes, particularly changes in precipitation.

A group of researchers, led by IPRC meteorology professor **Shang-Ping Xie** and including collaborators at NOAA's

Figure 1. Annual-mean projected **precipitation change** (in mm/month: green/gray shade and white contours. Note different contour intervals in the two panels). Top: AM2.1 simulation run with a uniform 2°C sea surface temperature (SST) increase; color contours represent presentday climatological rainfall [100 (purple), 200 (orange), and 300 (red) mm/month]. Bottom: CM2.1 A1B ensemble mean, featuring spatial patterns of SST (color contour interval = 0.25°C). Top panel shows greatest projected rainfall increase (green areas) for currently the wettest regions; bottom panel shows greatest projected increase in rainfall for regions with the largest projected meanincrease in SST. Geophysical Fluid Dynamics Laboratory (GFDL) and the National Center for Atmospheric Research (NCAR), has made important progress in identifying and explaining the robust large-scale regional patterns of climate change seen in global model projections.

For their study, they performed ensemble simulations with both the GFDL CM2.1 and NCAR CCSM3 global climate models. The runs covered roughly the first half of the 21st century and assumed a moderate-growth scenario for greenhouse gas emissions. The 50-year changes in the simulations were analyzed. Some of the team's key findings relate to regional changes in rainfall in response to the warming. A popular interpretation of such rainfall changes assumes spatially uniform warming and no circulation changes. This assumption results in a zero-order effect of just increasing atmospheric absolute humidity in accordance with the warming, magnifying present-day values of atmospheric moisture convergence and divergence. This leads to a tendency for present-day wet regions to get wetter and dry regions to get drier (Figure 1, top panel).





Cloud patterns over the Indo-Pacific region. Source: a rearranged image of "blue marble" stitched together from months of satellite observations by NASA Goddard Space Flight Center.

Xie and his colleagues show that this view has to be significantly modified in order to explain the actual changes seen for low-latitude regions in the warming simulations. In particular the geographical patterns of rainfall changes in the tropics and subtropics are strongly affected by modification in the low-level winds, which themselves are strongly linked to the gradients in the surface warming.

Xie found that the predicted geographical variations in surface warming are large. In fact, the difference between surface-temperature rise in locations with the least and the greatest warming in the tropics exceeds the magnitude of the mean tropical warming. Broadly speaking, Xie noted that regions with the greatest warming would become wetter, while those with little surface warming would become drier.

The influence of the spatial patterns of warming is evident in Figure 1, which compares the annual-mean rainfall change simulated in response to a uniform 2°C increase in sea surface temperature (top), and the change in the GFDL coupled model run that includes the spatial pattern in ocean warming (bottom).

Xie and his colleagues identified several characteristic regional patterns of warming and rainfall change in the simulations. First, the maximum sea surface temperature (SST) rise in the Pacific is along a broad band at the equator. This broad band of peak warming alters the atmospheric heating in the models significantly and anchors a rainband analogous to that occurring during an El Niño. The reasons for the broad band of maximum surface warming along the equatorial Pacific are present-day weaker winds, lower SST, and higher humidity along the equator, which render evaporation less efficient there than in the subtropics. Since evaporation is the major means by which the ocean balances heating due to greenhouse gases, the ocean surface in the equatorial region

will warm more than in the subtropics.

The subtropical oceans in the Northern and the Southern Hemisphere warm asymmetrically in response to the climate forcing. The north warms on average by 0.5°C more than the south. This asymmetry seems to be mostly the result of changes in the winds (Figure 2). The northeast trades weaken, leading to a warming of over 1°C in the Northern Hemisphere. The southeast trades in all three ocean basins, on the other hand, intensify, leading to cooling by evaporation and by mixing of cooler water from below, which keeps the warming below 1°C.

The stronger South Pacific trades create a cool patch in the southeastern corner that stretches westward and equatorward. The annual rainfall over the cool patch is projected to decrease compared to present-day rainfall. This means that Tahiti could get less rain in the future even though it lies beneath the South Pacific convergence zone. On the other side of the equator, the



Figure 2. Annual-mean changes in CM2.1 A1B: SST (color; °C) and surface wind velocity (m/s), along with scalar wind speed (contour interval=0.1 m/s). Zero contour is omitted for clarity.

warmer tropical-subtropical North Pacific could get more rain than today (Figure 1, bottom panel).

A third ocean warming pattern noted by Xie and his colleagues results in rainfall changes in the Indian Ocean and would affect the lives of billions of people. The tropical Indian Ocean generally becomes warmer, the warming in the models reaching 1.25°C from December to June. Overlayed on this average warming, is a yearly pattern during July–November that is similar to the present-day, rather infrequent Indian Ocean Dipole pattern. That is, model warming in the western Indian Ocean is amplified, reaching 1.5°C, while in the eastern Indian Ocean it reaches only around 0.5°C. This pattern emerges because strong easterly winds bring cold thermocline water to the surface off the Indonesian coast and pushes the warm equatorial water westward (Figure 3).

The projected Indian Ocean Dipole pattern can be expected to dramati-

cally shift rainfall over eastern Africa, India, and Southeast Asia. Indonesia and Australia could be more prone to drought, whereas parts of India and regions of Africa bordering the Arabian Sea could get more rain than today.

After publication in the Journal of Climate, this work attracted a commentary in the News and Views section of Nature Geoscience by University of Miami climate scientist **Amy Clement** and her colleagues: "The study by Xie and his colleagues lays the groundwork for increasing confidence in the pattern of projected tropical and subtropical ocean warming over the twenty-first century...Warming can have an immediate impact on local ecosystems, and coral reef ecosystems provide a poignant example of this."

This story is based on:

S.-P. Xie, C. Deser, G.A. Vecchi, J. Ma, H. Teng, and A.T. Wittenberg, 2010: Global warming pattern formation: Sea surface temperature and rainfall. *J. Climate*, 23, 966–986. IPRC-632.



Figure 3. August–October changes in CM2.1 A1B: (a) SST (color contour interval=0.125°C) and precipitation (green/gray shade and white contours at intervals of 20 mm/month) and (b) sea surface height (contour interval=1cm) and surface wind velocity (m/s).