South Pacific Rainfall in a Warming Climate

Image courtesy of NOAA

The main source of rainfall for the South Pacific island nations during austral summer is the largest rainband in the Southern Hemisphere, the South Pacific Convergence Zone (SPCZ). This rainband supplies water for agriculture in Northern Australia and drinking water for the many South Pacific islands. Because the overall amount of rainfall varies greatly over short distances, small shifts in the location of the rainband could have severe consequences for the vulnerable island nations already having to adapt to sea level rise.

Despite its importance, scientists know very little about how this 8,000-km-long rainband will respond to greenhouse warming. One reason why projections are so elusive is that state-of-the-art coupled general circulation models (GCMs), used for climate projections and assessments by the Intergovernmental Panel on Climate Change (IPCC), have trouble realistically simulating this hydroclimate phenomenon under present-day climate conditions.

Two years ago, an international team of scientists around IPRC's **Matthew Widlansky**, **Axel Timmermann**, and **Niklas Schneider** set out to explore why the rainfall response to greenhouse warming is so uncertain in the South Pacific island region—some climate models simulate more rainfall by the end of the 21st century, while others suggest much drier future conditions.

The impetus for this study then came during a workshop in the small island nation of Samoa where Widlansky and Timmermann, along with oceanographers **Matthieu Lengaigne** (L'Institut de recherche pour le développement, France) and **Wenju Cai** (Commonwealth Scientific and Industrial Research Organisation, Australia), discussed the uncertainty of rainfall projections for the region.

"It was at the Samoa meeting," Widlansky recalls, "that we realized just how little we know about climate change in the South Pacific, and that we have such fundamental questions as, why does the SPCZ exist?"

Storms in the South Pacific on 8 February 2012. Image courtesy of Digital Typhoon, National Institute of Informatics.

Back in Honolulu, the IPRC scientists invited **Matthew England**, co-director of the Climate Change Research Centre at the University of New South Wales (UNSW, Australia) and **Shayne McGregor**, a former IPRC postdoctoral fellow and now at UNSW. Together the team laid out a plan for a sequence of experiments to explore some of the unknowns about the SPCZ response to climate change (see 'Visiting Scholars' in *IPRC Climate,* vol. 11, no. 2, 2011).

The first step, the scientists decided, was to understand why climate models have difficulty simulating the present-day South Pacific rainfall. Since each coupled ocean-atmosphere GCM simulates unique sea surface temperatures (SSTs), which often deviate sharply from the observed SST pattern, the scientists thought removing SST errors might improve the climate simulations.

Their hunch was right. Forcing a hierarchy of atmospheric models with the observed SST pattern always yielded a diagonal rainband in the South Pacific, consistent with observations. Their model-simulated rainbands, moreover, were free of many errors typical of more complex coupled GCMs. For example, in their bias-corrected experiments, the so-called 'double-Intertropical Convergence Zone (ITCZ)' problem mostly disappeared.

Karl Stein, an oceanography doctoral student at the University of Hawai'i at Mānoa, then tested the effects of SST bias on the SPCZ's response to greenhouse-gas increases and also on the projected 21st century SST increase. Specifically, Stein conducted control and climate change experiments with a radiative flux corrected coupled GCM (CCSM3) to achieve more realistic present-day coupled SST patterns and

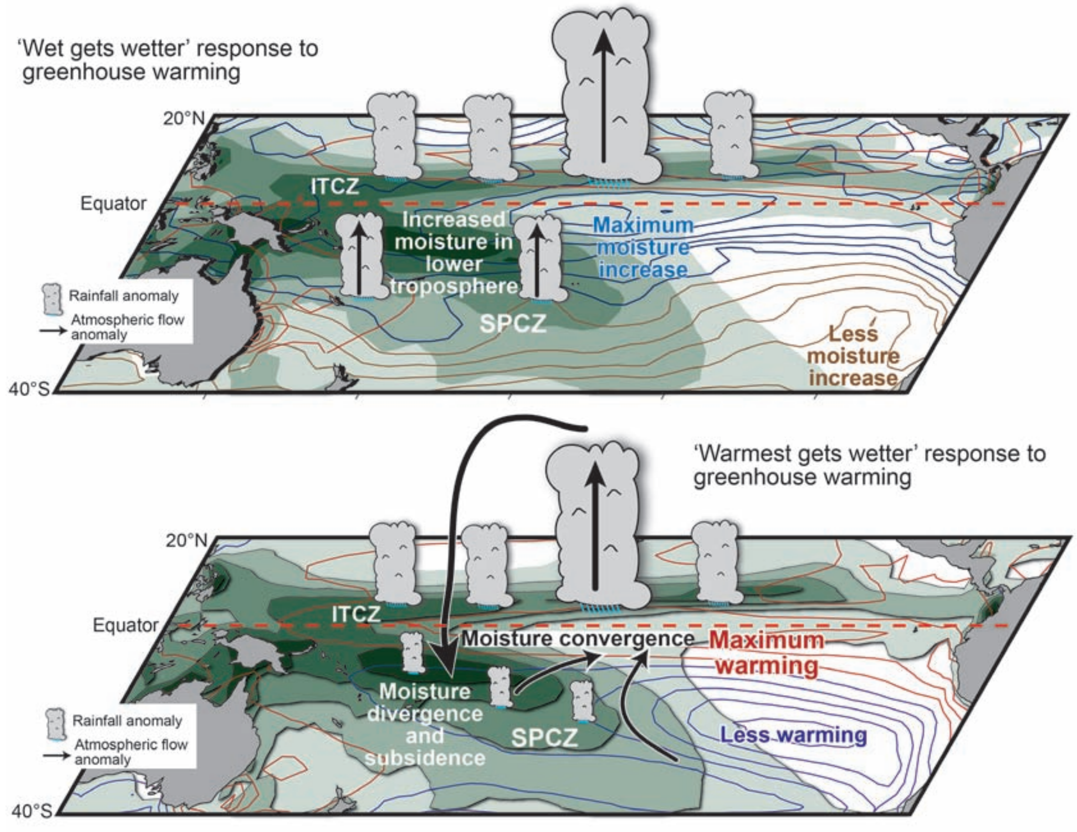

Figure 1. Illustration of the two opposing mechanisms that can impact rainfall rate in the South Pacific Convergence Zone (SPCZ), given the projected 21st century greenhouse warming. *Green shading* depicts the observed average rainfall during austral summer over the last 30 years (heavier rainfall indicated by *darker shading*).

Top: Rising tropical temperatures will lead to more water vapor in the atmosphere (*blue and brown contours*) which could bring about heavier rainfall in regions of converging winds such as the SPCZ. Some studies refer to this thermodynamic effect as the 'wet gets wetter' climate change mechanism.

Bottom: Most model simulations of climate change suggest the equatorial Pacific will warm faster (*red contours*) than the SPCZ region (*blue contours*). Such uneven warming is likely to pull the rainband away from its normal position, causing drying in the Southwest Pacific and more equatorial rainfall. This is a dynamic effect referred to as the 'warmest gets wetter' mechanism.

then compared the projected warming pattern to the standard CCSM3 greenhouse warming experiment. Both sets of experiments simulated a greater rise in SST along the equator than off the equator (a warming pattern noted in many studies, including the IPCC Fourth Assessment Report). This uneven heating between the SPCZ region and the equator, as the scientists later learned, is pivotal in determining how the rainband responds to greenhouse warming. Most importantly, Stein's experiments demonstrated that the warming pattern is robust, even when improvements are made to the coupled model's SST climatology.

In further experiments with corrected SST biases, the team identified two competing mechanisms impacting future rainfall trends in the South Pacific: an increase due to overall warming and a decrease due to changes in atmospheric water transport associated with the projected warming pattern.

"We have known for some time that rising tropical temperatures will lead to more water vapor in the atmosphere," says Timmermann. "Abundant moisture tends to bring about heavier rainfall in regions of converging winds such as the SPCZ." Some studies refer to this as the 'wet gets wetter' climate change mechanism (i.e., a thermodynamic effect illustrated in Figure 1, *top*).

"Nearly all climate-change model simulations suggest that warming will not be uniform, but rather that the equatorial Pacific is likely to warm faster than the SPCZ region. This warming pattern is likely to pull the rainband away from its normal position, causing drying in the Southwest Pacific and more equatorial rainfall," Timmerman explains. Climate scientists refer to this as the 'warmest gets wetter' mechanism (i.e., a dynamic effect illustrated in Figure 1, *bottom*).

Widlansky adds, "When we evaluated the latest climate change experiments being conducted by international climate modeling groups for the forthcoming IPCC Fifth Assessment Report, we saw that these competing mechanisms cause the different SPCZ rainfall projections among models."

Depending upon the degree of tropical warming expected this century, the scientists found that one or the other mechanism is more likely to win out (Figure 2). With moderate warming, weaker SST gradients are likely to shift the rainband towards the equator, potentially causing drying during summer for most Southwest Pacific island nations. For much higher warming possible by the end of this century, the net effect of the opposing mechanisms is likely a shift towards more rainfall for the South Pacific islands.

"To be more definite in our projections, however, we need more extensive observations on the formation of clouds and rainfall in the South Pacific and their response to such climate phenomena as El Niño. Before we have more confidence in our calculations of the delicate balance between the two climate change mechanisms, we need to be able to simulate cloud formations more realistically," says Timmermann.

This story is based on

Widlansky, M.J., A. Timmermann, K. Stein, S. McGregor, N. Schneider, M.H. England, M. Lengaigne, W. Cai, 2012: Changes in South Pacific rainfall bands in a warming climate. *Nature Clim. Change*, doi:10.1038/NCLIMATE1726. IPRC-923.

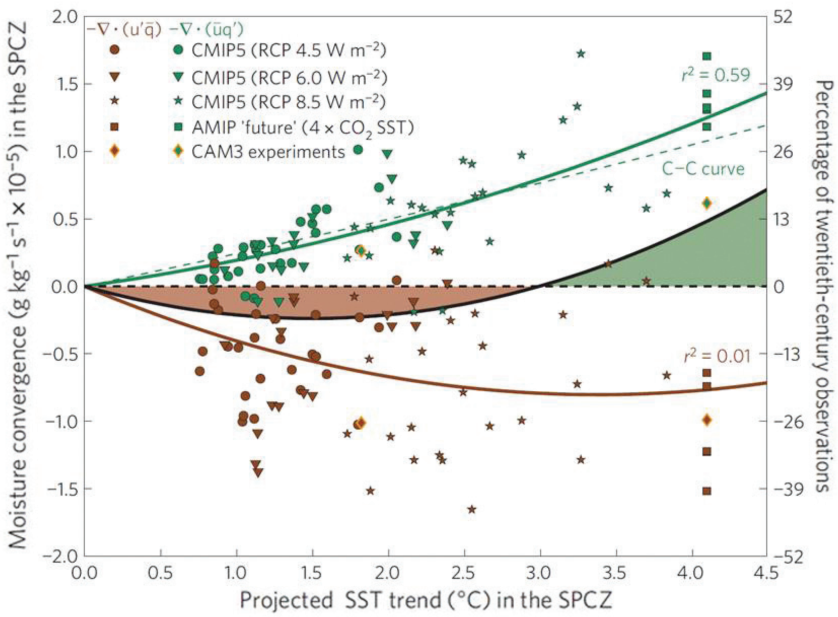

Figure 2. Projected net moisture flux convergence in the SPCZ as a function of SST increase. Green and brown curves represent the best fit, using a 2nd order polynomial, for each model's thermodynamic and dynamic moisture flux effects, respectively. The *shaded curve* represents the sum of the *green* and *brown curves* and shows the multi-experiment projection estimate of net moisture flux convergence, which is a good indicator for the difference between rainfall and evaporation (except for eddy contributions).