Is the Threshold Rising for Tropical Convection?

Rain shaft over Man-of-War Bay: Credit NOAA

Deep, moist convection over the ocean tends to occur only when surface temperatures exceed about 27°C. What will happen to this threshold for convection as global temperatures rise? If the threshold were to stay around 27°C, then the region of the ocean surface characterized by deep convection would expand as climate warms. A definitive answer has eluded scientists because reported measurements of the tropical atmosphere temperatures conflict with each other, and the mechanism determining this threshold has not been well understood.

Nat Johnson and **Shang-Ping Xie** at the IPRC have now demonstrated that even though over the past 30 years sea surface temperature (SST) and the threshold for convection have varied greatly from year to year, they have varied in tandem, and over the long term both have risen. This implies that SST and the convection threshold are closely linked.

At the center of their study is the theory of moist adiabatic lapse rate (MALR) adjustment. "According to this theory, when surface temperatures rise, so should the temperature in the upper troposphere," explains Johnson. "We hypothesized that the convective threshold is closely linked to tropical mean SST and should rise along with ocean temperatures because the moist adiabatic lapse rate varies with the underlying SST."

Radiosonde and satellite measurements of the tropospheric temperature, however, have given conflicting pictures, with some studies actually indicating that the upper troposphere has not warmed since 1979. If the warming of the upper troposphere is, in fact, substantially lower than expected by MALR adjustment, then the tropical atmosphere would be more unstable and more frequent convection could be expected.

Rather than relying on satellite and radiosonde measurements of the upper tropospheric temperature, Johnson and Xie used indirect measures of atmospheric stability, analyzing changes in the annual-mean tropical rainfall from 1979 to 2009 in two widely used

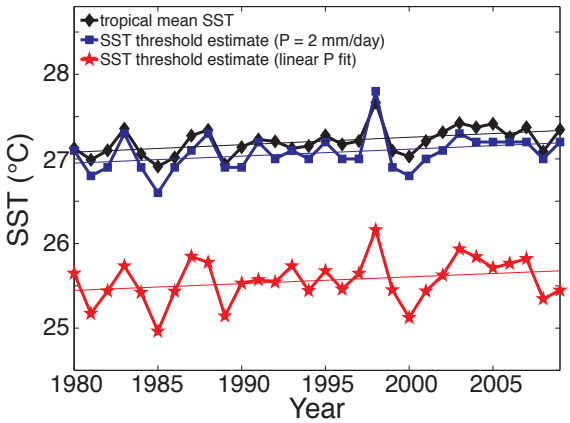

Figure 1. Time series of tropical (20°S to 20°N) annual mean SST (black) and two estimates of the SST threshold for convection (blue and red) together with their linear trends. The blue curve is estimated from the lowest SST at which the mean precipitation rate (*P*) exceeds 2 mm/day; the red curve is estimated from *P* that was approximated as a linear function of SST above a threshold. The linear trends for the tropical mean SST and SST threshold estimates are all approximately 0.1 °C/decade.

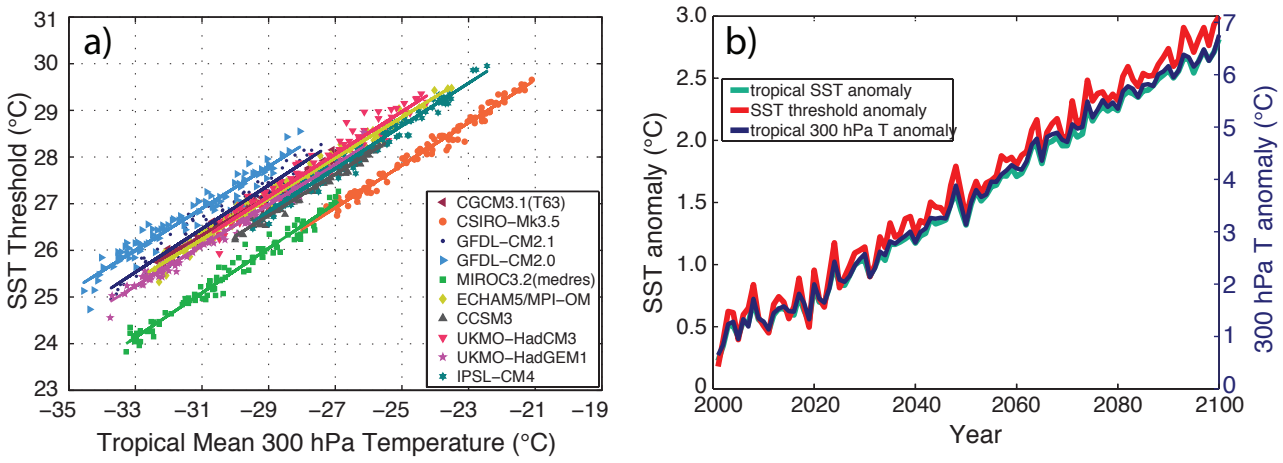

Figure 2. The relationship between the SST threshold for convection and upper tropospheric temperature in global climate models. (a) Scatter plot of SST threshold against tropical mean 300 hPa temperature with regression lines for each of 10 CMIP3 models under emissions scenario A1B in simulations of the 21st century. (b) Time series of the CMIP3 ensemble-mean deviations from the 1961–1990 averages for tropical mean SST (green), SST threshold for convection (red), and tropical mean 300 hPa temperature (blue). The right y-axis for 300 hPa temperature has been scaled to follow MALR adjustment of tropical mean SST (left y-axis); thus, the overlap among the three curves suggests that the convective threshold is following MALR adjustment of the tropical mean SST.

global precipitation products, the Global Precipitation Climatology Project and the Climate Prediction Center Merged Analysis of Precipitation. They computed the convection threshold in two ways: (1) by finding the lowest SST for which the mean precipitation rate exceeds 2 mm/day, and (2) by approximating the precipitation rate above a threshold as a linear function of SST. Although the precise value of the SST convective threshold depended to some extent on the definition employed, the variability did not: both methods show a remarkable correspondence between mean tropical SST and the convective threshold (Figure 1) and both methods reveal an upward trend of about 0.3°C over the 30 years. Results obtained with the two precipitation products are similar.

Johnson and Xie then examined the relationship between the convection threshold, tropical mean SST, and tropical mean 300 hPa temperatures in 20th and 21st century climate simulations in ten global climate models from the World Climate Research Program Coupled Model Intercomparison Project 3 (CMIP3) archive.

The model simulations, including the 21st century runs that featured an approximate doubling of atmospheric CO_2 concentrations under rapid world economic growth (emissions scenario A1B), show a close correspondence both between the convective threshold and tropical mean SST and between the convective threshold and tropical mean 300 hPa temperature (Figure 2a), supporting the idea that the convective threshold is responding to MALR adjustment of a warming tropical troposphere. Thus, MALR adjustment theory, global climate model simulations, and observations are all in agreement that the upper tropospheric temperature is rising more rapidly than surface temperatures. Figure 2b shows the mean tropical SST anomaly and determined threshold temperatures rising together through the 21st century in the CMIP3 ensemble mean results. The 300 hPa mean tropical temperature in the ensemble mean also rises in tandem with the mean SST, but at almost three times the rate.

"If moist instability would be increasing as tropical oceans warm with global warming, then we could see more frequent tropical cyclones and an expansion of the regions and seasons in which tropical cyclones occur. The close correspondence that we noted between tropical mean SST and the convective threshold, however, shows the convective stability of the tropical atmosphere has changed little over 30 years, despite rising SST," explains Shang-Ping Xie. "The study thus provides some reassurance that rising tropical ocean temperatures with global warming will not by itself cause substantially more tropical cyclones."

This story is based on

Johnson, N. C., and S.-P. Xie, 2010: Changes in the sea surface temperature threshold for tropical convection *Nature Geoscience*, **3** (12), 842–845.