Convergence and Cold Pools in the ITCZ

Oregon State University
College of Earth, Ocean, and Atmospheric Sciences

Eric D. Skyllingstad and Simon P. de Szoeke

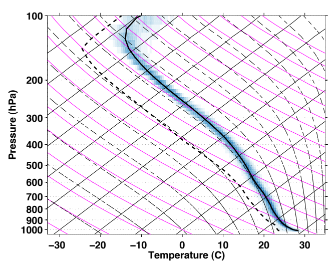
Introduction

We often observe multiple scales of convection in the tropics that do not have obvious synoptic organization. One exception is the Inter-Tropical Convergence Zone (ITCZC) where convective systems can organize in a line, frequently over a region of elevated sea-surface temperature (SST). But even in the ITCZ, mesoscale convective clusters split off from the primary region of convergence. These disturbances form in response to instability processes, most notably barotropic instability, and occasionally lead to tropical storm formation away from the ITZC. The ensemble of mesoscale convection may also contribute to background baroclinic instability. Dynamical instability and convection have been addressed in many studies (see Yokota et al. 2015 for recent work). **Here, we study how convective cold pools may modulate large-scale convective organization within the ITZC, using idealized numerical simulations with a high-resolution cloud resolving model.**

Methods

Experiments are conducted using a cloud resolving, large-eddy simulation model described in Skyllingstad and de Szoeke (2015). The model uses a standard dynamical core based on a flux form of the equations of motion and a split time compressible solver. Radiation is parameterized using RRTM and cloud microphysics are based on the 2nd moment scheme from Thompson et al. (2008).

Initial conditions are based on an average profile from the DYNAMO field program as shown below.

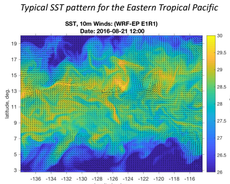


The shaded color represents the observed temperature histograms at each level and the solid line is the average value. Dew point values in the model are prescribed using values plotted as the dashed line.

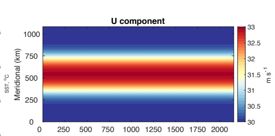
Cases are considered for a rectangular domain with dimensions of 2160 km in the zonal direction and 1080 km in the meridional direction and grid spacing of 3 km. A vertical grid with 120 levels is applied with spacing increasing exponentially from 10 m at a level of 10 m to 120 m at ~325 m height. Above ~11 km, the grid expands to 680 m near the model top at 21 km. Rayleigh damping is applied over the top 1/5 of the domain to absorb vertically propagating internal gravity waves.

SST conditions are set using the observed Eastern Tropical Pacific SST field as a guideline as shown below. For our simulations, we use an idealized version of SST with temperatures ~3 °C higher than the surrounding water over a 500 km wide band extending uniformly in the zonal direction. This is clearly simplified from the actual ocean, but provides a similar scale forcing. Winds are set to a uniform value of 1 m s^{-1} and with experiments starting around 6:00 am local time.

Typical SST pattern for the Eastern Tropical Pacific

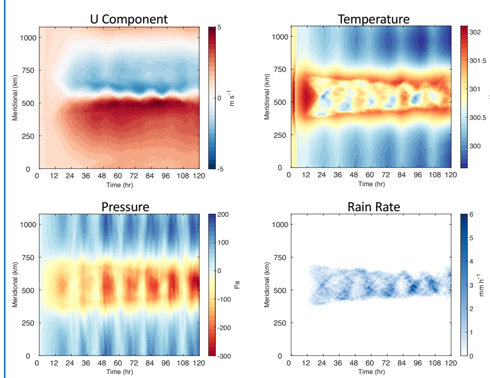


Fixed SST for simulations



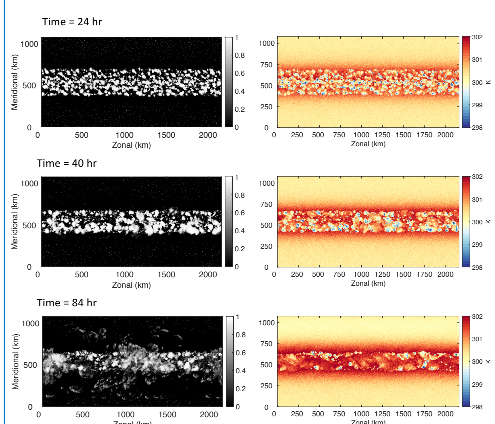
ITCZ Flow Evolution

Time-latitude plots of the surface zonal wind u, air temperature, pressure, and rainfall provide an overview of the simulated ITCZ. Warming of the surface air reduces the local density resulting in a decrease in the hydrostatic pressure. In response, a convergence zone develops and the inflow gradually turns to the right in response to the Coriolis term. Within 24 hrs, the flow is near geostrophic balance with an easterly jet along the northern edge of the warm water and a westerly jet along the southern edge. Convection develops in response to meridional convergence and higher moist static energy over the warm patch and forms clusters that vary in strength with a period slightly shorter than the diurnal cycle. There are 7 low pressure pulses over the 5 day period. Periods of enhanced convection are indicated by increased precipitation and cooler surface air temperature from cold pools.

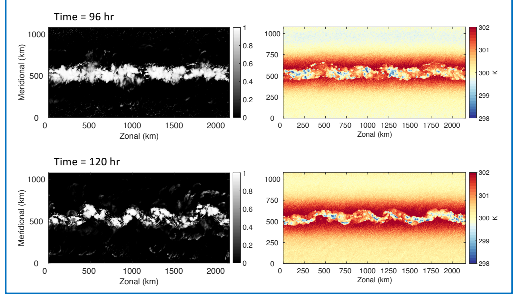


Convective Organization

Plots of the cloud cover and surface air temperature show how the convective clusters develop over time. Initial convection is generated over the warm band as a relatively uniform set of cells with scales of about 20-50 km. By hour 40, the effects of asymmetry in the meridional flow cause enhancement of convection along the southern edge of the warm band. Pulsing of the convection with a period less than diurnal leads to periods of scattered, weak cells as shown at hour 84. Throughout this early period of development, convection is divided into a north and south line, with the southern line often stronger than the north. This is shown in the temperature plot above by the average cold pool location displaced southward.



As the convection contracts further, the two lines merge into a single convective system, which begins to show a wave structure by hour 120 indicating the onset of barotropic instability.

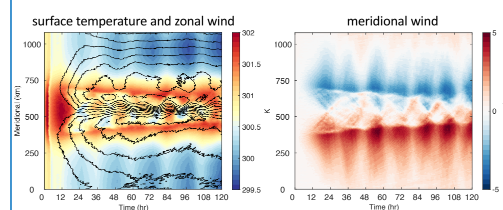


Discussion and Questions

We hypothesize that the convective clusters and pulsing behavior of the simulated ITCZ is generated by the interaction of barotropic instability with convective cold pools and horizontal shear induced by the geostrophic balanced wind. One necessary condition for barotropic instability relates the meridional gradients of temperature and zonal wind components such that:

$$\left(\frac{\partial\theta}{\partial y}\right)\left(\frac{\partial U}{\partial y}\right) < 0.$$

A rough estimate of this condition can be assessed by contours of u wind over the surface air temperature (left, below). Cold pools cool the air just south of the main zonal velocity gradient between the easterly and westerly jets. As a consequence, the barotropic condition is satisfied for the strong meridional gradient north of the cold pools for most of the simulation, but with a maximum negative value around hour 96 as the convergence zone contracts to a minimum width. Asymmetry in the meridional flow because of the beta effect is evident in the v velocity component and is responsible for stronger convection along the southern side of the warm SST band.



These preliminary simulations suggest that SST plays a significant role in controlling the ITCZ and mesoscale organization of convective clusters is likely a key element in the formation of barotropic disturbances. Clusters of cold pools appear to enhance the meridional gradients, which can lead upscale to baroclinic instability and increased synoptic eddies, further modifying subsequent convective organization. Questions that we plan to pursue include:

- Do convective pulses represent an overlap of the diurnal cycle with barotropic wave development?
- How does the instability change with SST anomaly magnitude and width?
- What effect does background wind have on instability?
- How does the geostrophic circulation affect the SST anomaly and is there a coupled response?

References

Yokota, S., H. Niino, and W. Yanase, 2015: Tropical cyclogensis due to ITCZ breakdown: Idealized numerical experiments and a case study of the event in July 1988. *J. Atmos. Sci.*, *72*, 3663-3684.

Skyllingstad, E. D., and S. P. de Szoeke, 2015: Cloud-resolving large-eddy simulation of tropical convective development and surface fluxes, *Mon. Wea. Rev.*, *143*, 2441-2458

Thompson, G., P. R. Field, R. M. Rasmussen, and W. D. Hall, 2008: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part II: Implementation of a new snow parameterization. *Mon. Wea. Rev.*, *136*, 5095-5115.