

James Russell | Research Statement

The dynamics of tropical weather systems on practically all spatial scales are still heavily debated topics. On the mesoscale, determining what combination of environmental structure and convective properties result in upscale growth of convective clouds into a mesoscale convective system (MCS) is a key unanswered question. On synoptic and larger scales, many phenomena do not have agreed upon propagation and instability mechanisms, but are often shown to be strongly associated with convective organization. Tropical weather systems directly impact the majority of human population and given their role on sub-seasonal to seasonal predictability globally, it is essential that their dynamics are well understood. My research focuses on bridging theory and observations to understand the dynamics of tropical systems and provide means to better predict their effects.

My current research focuses on the scale interactions between African Easterly Waves (AEWs) and convection. This work uses reanalysis products, numerical modeling with the Weather Research and Forecasting Model (WRF), and observations such as satellite-borne remote-sensing measurements and radiosonde soundings. The goals of this work are to understand 1) the role of diabatic and adiabatic processes in AEW dynamics, 2) how convection and the AEW vary between the land and ocean, and 3) how the organization of convection is affected by the AEW. Specifically this research is separated into three main components. The first analyzes the composite average potential vorticity (PV) structure and dynamics of AEWs in reanalyses. The second simulates individual AEWs with WRF to test the sensitivity of AEWs to convective processes. The third quantifies the role of individual MCSs on an AEW and investigates how the MCSs are organized by the AEW.

These studies show that a pre-existing mid-to-upper level AEW PV anomaly can be maintained by adiabatic processes. However, the low-level AEW grows by diabatic contributions to the PV, primarily through the release of latent heat from convection coupled with the AEW. Convection is then coupled with the AEW by modulation of parameters such as CAPE and synoptic scale forcing for vertical motion. Since convection produces a characteristic positive low-level PV tendency and occurs in all phases of the AEW, it promotes the growth of the trough but decay of the ridge. I hypothesize that this helps the transformation from wave-like to vortex-like structures. Some of these convectively coupled vortices may transform into tropical cyclones.

Future research avenues along this vein include investigating these results with observations from field program, and testing the above findings in idealized modeling studies. It is expected that observations will help us better understand whether variables such as heat sources, integral to such calculations of PV budgets, can be trusted. Historical experience shows that the best way to fully understand the dynamics of any system is to simplify the situation as much as possible and then examine the differences when processes are added or removed. Thus an idealized approach to examining AEWs and convection is of interest and will involve modifying idealized numerical models to simulate convection relative to the synoptic system.

Since AEWs play such a significant role in Atlantic tropical cyclone formation, my work has also focused on the role AEWs play in modulating TC formation. A re-examination of the connection between AEWs and TCs updated statistics connecting the two and used statistical methods such as resampling to show that only low-level AEW strength is correlated with TC genesis. Finally, an examination of the inter-annual variability of AEWs showed that the storm track had three distinct modes of variability, one of which is strongly connected to tropical cyclone formation and ENSO. At NC State, we are aiming to build on this work further. I am currently involved in writing an NSF proposal that will use a modeling approach to examine whether AEWs are important for TC genesis. We hope this will clarify the role AEWs play, specifically on the seasonal scale.

More broadly, I am interested in the role synoptic scale systems play in organizing a wide range of tropical convection, and will be writing proposals for research on such a topic. My approach will focus strongly on combining theory and observations. To do this, I will use data from field programs to compare cases where convection did or did not organize. This will vary from cases of tropical cyclogenesis, to cases of simple MCSs. A focus will be on understanding how synoptic systems support convection by modifying the environment. Combining such comparisons with modeling sensitivity studies will build a detailed picture of the processes at play and provide strong evidence for or against the hypotheses. My aim is for this to help address the question of how convection organizes in the tropics.

A key component of any research examining tropical systems is understanding the accuracy of the observations and numerical models involved. As such, I am interested in examining the validity of satellite-borne measurement systems and reanalysis products, especially in areas with sparse observational coverage. During earlier research conducted at the University of Oklahoma, I examined the biases and error in the Antarctic Mesoscale Prediction System (AMPS; an operational version of WRF producing forecasts for Antarctica). This analysis used dropsonde data from the Concordiasi field campaign to find and diagnose biases in WRF forecasts. Specifically, there were significant biases in the simulation of the extreme low-level inversions. Future work will use this background in the verification of cutting edge research tools like the Global Precipitation Measurement Mission (GPM) and the ECMWF's ERA-5 reanalysis. Satellite-borne measurements and field program data are essential for these analyses as there are typically little other data available.

In the long-term, my overarching goals are to improve understanding of the dynamics of tropical systems. This knowledge is then used by model developers to improve model components, and by individual forecasters to enhance their own forecasts. This will benefit a wide-range of end users from populations of countries these systems directly impact, to populations of countries downstream. My general approach to any problem is to combine theory and observations using a combination of field-program data, satellite-borne measurements, reanalyses, and modeling. Through this approach and with these goals I hope to positively impact as many people as possible with my research.