Cyclonic Vortices in the African Tropics

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Decades of meteorological research have produced a plethora of sophisticated conceptual models for midlatitude weather systems such as the Norwegian cyclone or the conveyor-belt models. For tropical climates, such models are generally more scattered. Arguably one of the most established and powerful concepts for low-latitude large-scale weather systems are equatorial waves based on linearized shallow-water systems as first discussed by Yanai, Matsuno and others in the 1960s. The simplest forms assume a weak horizontal temperature gradient and a resting basic state. All solutions decay away from the equator and can be separated into Kelvin, equatorial Rossby, mixed Rossby-gravity and inertia-gravity waves – all with their own characteristic patterns of geopotential, temperature, and wind perturbations. As the waves modulate convergence and divergence, they can couple with deep moist convection and the energy released maintains the waves against friction. This has led to the term convectively coupled equatorial waves (CCEWs). CCEWs can be identified from satellite-based outgoing longwave radiation (OLR) fields using space-time filtering. Interestingly, climatological results in wave frequency-zonal wavenumber space show two areas that are not solutions of the shallow water system: Large-scale, slow, eastward-moving signals associated with the Madden-Julian Oscillation (MJO) and relatively small, fast, and westward moving so-called “tropical disturbances” (TDs).

For the African tropics, boreal summer is characterized by the West African monsoon (WAM). Large differences in temperature between the hot Sahara and cooler southern West Africa lead to the thermal African easterly jet (AEJ). Baroclinic-barotropic instability supports the formation of synoptic-scale African easterly waves (AEWs), which are intimately coupled with convection, particularly over the Sahel. These are usually characterized by two cyclonic vortices at 850 hPa straddling the AEJ to the north and south. There are sporadic reports in the literature of single vortices or slow-moving cyclonic-anticyclonic vortex couplets, but the involved physical mechanisms are unclear. AEWs, tropical cyclones and single vortices are typically subsumed under the TD category.

In June-July 2016 the DACCIWA (Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa) project organized a major international field campaign in southern West Africa including measurements from aircraft, ground, and radiosondes. Careful daily synoptic analyses were produced to guide flight-planning and post-analysis of observations. The results are a strong illustration of the richness of features encountered over the African tropics. Three types of behaviors can be distinguished: The first type is classical AEWs with a northern and southern cyclonic vortex. They usually have a discernable signal in vorticity, wind, and precipitation fields. Particularly before the monsoon onset, a second type, single cyclonic vortices, occur at different latitudes with different propagation speeds. These are often related to long-lived mesoscale convective systems (MCSs) and thus modulate rainfall on the regional scale. One particular example during the DACCIWA period caused record precipitation in southeastern Nigeria. Despite the low latitude, the vigor and spatial extent of the convection was sufficient to create a mesoscale vortex. The third type, which appears to be rarer and the climatological and dynamical characteristics of which are barely covered in the literature, are jointly propagating cyclonic and anticyclonic vortices, which create an anomalous westerly flow in between them. More work is needed to develop a consistent all-encompassing conceptual models for cyclonic vortices in the African tropics, particularly as there are indications that regional-scale predictability is enhanced when synoptic systems are active.