Tropical Jets and Disturbances

Introduction

The tropical circulations and jets we have discussed have wavelengths ranging from the highest ends of the synoptic scale up to the planetary scale. In this lecture, we introduce three tropical circulations and jets that occur on the smaller ends of the synoptic scale: African easterly waves and the tropical and African easterly jets. We also introduce a phenomenon that is uniquely associated with the African easterly jet, the Saharan air layer, that significantly influences the tropical North Atlantic Ocean's climatology.

Key Questions

- What are the salient characteristics of African easterly waves?
- How are African easterly waves initiated, and how do they gain energy?
- What are the salient characteristics of the tropical easterly jet?
- What are the salient characteristics of the African easterly jet?
- What are the physical processes responsible for the African easterly jet's existence and structure?
- What are the salient characteristics of the Saharan air layer?
- How is the Saharan air layer initiated, and how does its structure evolve as it moves westward over the tropical North Atlantic Ocean?

African Easterly Waves

African easterly waves (AEWs) are westward-travelling waves that originate over northern Africa primarily between June and October. They have horizontal wavelengths of ~2500 km, periods of 3-5 days, and move westward at 5-8 m s^{-1} (or ~500-800 km per day). AEWs form in response to latent warming associated with mesoscale convective systems that form in response to upslope flow along higher terrain in eastern Africa. They grow at the expense of the African easterly jet (AEJ) through a combined barotropic-baroclinic energy conversion process. AEWs have largest amplitudes at ~650 hPa and near the African west coast, and AEWs generally decay after emerging over the eastern North Atlantic Ocean. AEWs tilt against the vertical wind shear; because the climatological vertical wind shear over Africa is easterly due to the AEJ, AEWs typically tilt to the east with increasing height. Substantial variability in AEW structure and evolution exists from (a) variability in the side of the AEJ on which they form and (b) AEJ intensity and structure. AEWs, particularly those that form in moist environments south of the AEJ, are the primary seedling disturbances for tropical cyclone formation in the north Atlantic and eastern north Pacific Ocean basins.

Tropical Jet Streams

Tropical Easterly Jet (TEJ)

The TEJ is an upper-tropospheric (~100-150 hPa) easterly jet that extends across the tropics from the eastern Indian Ocean to western Africa. The jet's latitudinal width is approximately 20-30°. Maximum wind speeds associated with the jet are on the order of 35-40 m s^{-1} and are typically found between 5-10°N from southern India toward the east coast of Africa. The TEJ is found on the southern periphery of the upper-tropospheric anticyclone associated with the Asian monsoon to which it is intricately linked. The TEJ is weak when the monsoon is weak and strong when the monsoon is strong, suggesting that variability in the monsoon also modulates variability in TEJ strength. The jet becomes established once the monsoon has started for the season and decays once the monsoon has ended for the season; thus, it is a salient feature of the tropics only during Northern Hemisphere summer. Thunderstorms preferentially form in the TEJ's right-entrance and left-exit regions, the jet quadrants favoring upper-tropospheric divergence. The TEJ's right-entrance region corresponds with the upward branch of the Walker circulation that extends from southeast Asia eastward across the Pacific Ocean.

African Easterly Jet (AEJ)

The AEJ is a midtropospheric jet located over much of tropical northern Africa during Northern Hemisphere summer. The AEJ has maximum (climatological) easterly wind speeds of >15 m s^{-1} (~10-12 m s^{-1}) along 10-15°N between 700-600 hPa. It exhibits large vertical and horizontal wind shears. The vertical wind shear associated with the AEJ is crucial to thunderstorm organization and squall-line formation. Both horizontal and vertical wind shears are important for AEW growth through barotropic and baroclinic instability. AEWs grow at the expense of the AEJ, with the AEJ being weakened by AEWs.

The AEJ is maintained by two diabatically driven meridional circulations. The first is characterized by the meridional contrast in sensible heating between the warm, dry Sahara Desert to the north and cooler, moister Sahel and equatorial Atlantic Ocean to the south. This results in a positive meridional potential-temperature gradient that, through thermal-wind balance, is associated with the strongly vertically sheared easterly zonal wind between 850-650 hPa associated with the AEJ. The second is associated with thunderstorms that result in upper-tropospheric latent warming equatorward of the AEJ that is absent poleward of the AEJ. This leads to a negative meridional potential-temperature gradient that, from thermal-wind balance, is associated with the observed upper-tropospheric westerly vertical wind shear with the AEJ.

The AEJ both influences and is influenced by precipitation variability in northern Africa. To the former, the AEJ is associated with an ageostrophic circulation that enhances upward motion and thunderstorms to its south and downward motion to its north. To the latter, reduced precipitation reduces soil moisture content across the southern Sahara Desert and northern Sahel regions of northern Africa, permitting stronger near-surface sensible heating and thus deeper mixed layers. This reduces the meridional distance between where sensible warming is maximized (to the north) and minimized (to the south), thus increasing the meridional potential-temperature gradient's magnitude and by extension the AEJ. Conversely, enhanced rainfall in this region is generally associated with a weaker AEJ by weakening the magnitude of the meridional potential-temperature gradient.

The Saharan Air Layer (SAL)

Strong sensible warming over the arid land mass of the Sahara Desert over a two- to three-day period results in the formation of a mixed layer with very large potential temperature. The base of this mixed layer rises as it is advected toward the west coast of Africa. Over the Atlantic Ocean, the hot, dry SAL air mass results in the formation of a temperature inversion atop the cooler, moister boundary layer. This inversion is located near 850 hPa near the coast of Africa and higher altitudes to the west. The top of the SAL is located near

500-550 hPa and is characterized by a weak temperature inversion corresponding to the upper limit of the deep mixing over the Sahara Desert. Air parcels within the SAL tend to be significantly drier than those of the rest of the tropics. The northern and southern boundaries of the SAL are typically between 25-30°N and 10-15°N, respectively, and its southern edge resembles an airmass boundary. The periodicity of the SAL is approximately 3-5 days, its horizontal scale is approximately 2000-3000 km, and it moves westward at a rate of approximately 500-700 km per day. The SAL is often accompanied by Saharan dust that propagates westward with the AEJ and prevailing easterlies across the tropical North Atlantic; stronger heating that permits deeper mixing and stronger AEJs also tends to promote greater kick-up of dust from the underlying surface into the air. The aerosol forcing of this dust can influence the strength of the meridional temperature gradient associated with the AEJ. Dust outbreaks associated with the SAL can happen throughout the year but are most common during the summer months. The dust's refractive properties allow us to monitor SAL events using satellite imagery.

Given its significant dryness and, through its association with the AEJ, characteristic strong easterly vertical wind shear, both of which are detrimental to tropical cyclones, one might think that the SAL is detrimental to tropical cyclones. However, the SAL's impacts on tropical cyclone development are not well understood. On an interseasonal basis, higher dust activity associated with a stronger SAL and AEJ may result in cooler tropical Atlantic sea-surface temperatures and reduced tropical cyclone activity. On an intraseasonal basis, numerous studies have hypothesized that the SAL may positively or negatively influence the development of a tropical cyclone. To the former, the SAL helps to focus and support convection along its leading and southern borders in a moist environment characterized by large-scale cyclonic rotation. Further, a stronger SAL generally is associated with a stronger AEJ and thus enhanced energy conversation associated with a disturbance's initial growth. In turn, the AEJ's transverse circulation is hypothesized to aid the development of both the disturbance and its associated thunderstorm activity, and the AEJ may also enhance large-scale cyclonic rotation (associated with the jet's horizontal wind shear) in the vicinity of developing disturbances. If such findings are true, then the large-scale environment rather than the SAL may be the primary limiting factor upon tropical cyclone development in regions in which the SAL is present. However, other studies suggest that the SAL suppresses thunderstorms, increases the vertical wind shear through its connection to a stronger AEJ, and fosters enhanced downdraft activity and associated lower-tropospheric divergence, all of which are detrimental to tropical cyclone formation. Thus, much work remains to precisely understand how the SAL influences tropical cyclone development.

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