Tropical Jets and Disturbances

Introduction

In previous lectures, we alluded to several types of disturbances found across the tropics, including the monsoon trough and intertropical convergence zone, that arise as a function or reflection of convergent flow across the tropics. Tropical cyclones, particularly in the western Pacific and Indian Oceans, commonly form out of one of these features. Before we proceed into the second half of the course and our studies on tropical cyclones, however, it is important for us to consider other types of tropical disturbances and jets that influence tropical cyclone activity. We also return to the concept of the tropical easterly jet, first introduced in our monsoons lecture, and further discuss its structure and impacts.

Key Concepts

- What is an African easterly wave? How do they form, grow, and decay?
- What are the African and tropical easterly jets and how do they influence easterly waves and the meteorology of Africa?
- What is the Saharan air layer and what are its characteristics?

African Easterly Waves

African easterly waves, or AEWs, are westward-travelling waves that originate over northern Africa primarily between June and October. They have approximate horizontal wavelengths of 2500 km, periods of 3-5 days, and move westward at a rate of 5-8 m s^{-1} (or 500-800 km per day). Previous theories for AEW formation suggested that they formed in response to the breakdown of the ITCZ or the growth of instabilities associated with the African easterly jet (AEJ). Current theory, however, suggests that AEWs form in response to latent heating associated with mesoscale convective systems that form along higher terrain in eastern Africa. They grow at the expense of the AEJ via a combined barotropic-baroclinic energy conversion process. They reach their largest amplitude near the west coast of Africa and generally decay after emerging over the eastern Atlantic Ocean 6-8 days after their formation. Largest wave amplitudes are found at approximately 650 hPa and the waves exhibit a vertical tilt against the shear vector; i.e., for easterly vertical wind shear, AEWs tilt to the east with increasing height. Substantial variability in AEW structure and evolution exists due to (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, serve as 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 atop the Tibetan plateau associated with the Asian monsoon. Indeed, the TEJ is intricately linked to the Asian monsoon and its divergent upper-tropospheric anticyclone. 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.

Deep, moist convection preferentially forms in the right entrance and left exit regions of the TEJ, or those in which upper-tropospheric divergence is promoted. The right entrance and left exit jet regions are typically located over southeast Asia to the northeastern Indian Ocean and central to western Africa, respectively. The right entrance region of the jet corresponds with the upward branch of the Walker circulation that extends from southeast Asia eastward across the Pacific Ocean. Variability in TEJ structure, intensity, and location can impact deep, moist convection initiation.

African Easterly Jet (AEJ)

The AEJ is a middle tropospheric 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 deep, moist convection organization and squall line initiation. Both horizontal and vertical wind shears are important for AEW growth via barotropic and baroclinic instability. AEWs grow at the expense of the AEJ, or, put another way, AEJ strength is modulated (i.e., weakened) by AEWs. The AEJ plays a crucial role in the West African monsoon system and is largely in geostrophic balance.

The AEJ is associated with an ageostrophic circulation that enhances upward motion and deep convection south of the jet and downward motion along and north of the jet. It is maintained by two separate diabatically forced meridional circulations. The first, associated with dry convection in the Sahara, is characterized by the contrast in sensible heating between the warm, dry Saharan air over northern Africa and cooler, moister air at equatorial latitudes. This contrast results in a positive meridional potential temperature gradient that brings forth the strongly vertically sheared easterly zonal wind between 850-650 hPa associated with the AEJ. The second is associated with deep, moist convection that leads to upper tropospheric heating equatorward of the AEJ. The observed upper-tropospheric westerly vertical wind shear with the AEJ results from the reversal of the meridional potential temperature gradient associated with this heating at equatorial latitudes.

Significant intraseasonal and interseasonal variability in the AEJ exists due to rainfall variability across northern Africa. Reduced precipitation reduces soil moisture content across the southern Sahara and northern Sahel regions of north Africa, permitting stronger near-surface sensible heating and thus deeper mixed layers. The AEJ tends to be stronger when sensible heating is strongest and mixed layers are deepest over these regions. Such conditions lead to an enhanced meridional temperature gradient (and, subsequently, stronger AEJ) between the Sahara and equatorial regions of Africa. The AEJ tends to be weaker when sensible heating is weak and mixed layers are shallow, thus weakening the meridional temperature gradient (and, subsequently, AEJ) across northern Africa.

The Saharan Air Layer (SAL)

Karyampudi and Carlson (1988) describe the formation, evolution, and structural characteristics of the SAL and its associated elevated mixed layer. Strong sensible heating over the arid land mass of the Saharan desert over a two-to-three day period results in the formation of a mixed layer with very warm 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 altiudes 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. 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 a mid-latitude front or baroclinic zone. 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 and can, in rare occasions, extend across the Atlantic to North America. Refractive properties of the dust enable us to monitor SAL events using satellite imagery.

The impacts of the SAL 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, though it is not yet clear whether the link is causal. On an intraseasonal basis, numerous studies have hypothesized that the SAL may positively or negatively influence the development of a tropical cyclone. Karyampudi and Carlson (1988) and Braun (2010) suggest that the SAL helps to focus and support convection along its leading and southern borders in a moist, cyclonic vorticity-rich environment. Further, a stronger SAL generally leads to a stronger AEJ and thus enhanced energy conversations associated with initial disturbance growth. The AEJ's thermally indirect transverse circulation is hypothesized to aid the development of both deep, moist convection and the disturbance. The AEJ may also enhance background cyclonic vorticity (as manifest through the horizontal shear of the jet) 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. By contrast, Dunion and Velden (2004) suggest that the SAL suppresses deep, moist convection, enhances vertical wind shear via a stronger AEJ, and fosters enhanced downdraft activity and reduced convective available potential energy. As a result, much work remains to be able to precisely understand how the SAL influences tropical cyclone development.

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