Clouds in Tropical Cyclones

Robert A. Houze Jr.

Abstract

Clouds within the inner regions of tropical cyclones are unlike those anywhere else in the atmosphere. Convective clouds contributing to cyclogenesis have rotational and deep intense updrafts but tend to have relatively weak downdrafts.

What's special about clouds in TCs?

Within the eyes of mature tropical cyclones, stratus clouds top a boundary layer capped by subsidence. An outward-sloping eyewall cloud is controlled by adjustment of the vortex toward gradient-wind balance, which is maintained by a slantwise current transporting boundary layer air upward in a nearly conditionally symmetric neutral state. This balance is intermittently upset by buoyancy arising from high-moist-static-energy air entering the base of the eyewall because of the radial influx of low-level air from the far environment, supergradient wind in the eyewall zone, and/or small-scale intense subvortices. The latter contain strong, erect updrafts.

Several types of clouds exist in TCs, forming through different processes.

Graupel particles and large raindrops produced in the eyewall fall out relatively quickly while ice splinters left aloft surround the eyewall, and aggregates are advected radially outward and azimuthally up to 1.5 times around the cyclone before melting and falling as stratiform precipitation.

Microphysical characteristics of TC clouds.

Electrification of the eyewall cloud is controlled by its outward-sloping circulation.

Electrification in TC eyewall clouds.

Outside the eyewall, a quasi-stationary principal rainband contains convective cells with overturning updrafts and two types of downdrafts, including a deep downdraft on the band's inner edge.

Principal rainband within TCs.

Transient secondary rainbands exhibit propagation characteristics of vortex Rossby waves.

Propagating secondary rainbands linked to vortex Rossby waves.

Rainbands can coalesce into a secondary eyewall separated from the primary eyewall by a moat that takes on the structure of an eye. Distant rainbands, outside the region dominated by vortex dynamics, consist of cumulonimbus clouds similar to non–tropical storm convection.

Reorganization of rainbands and secondary eyewalls.

Effects of Sea Spray on Tropical Cyclone Intensity

Edgar L. Andreas[1] and Kerry A. Emanuel[2]

Abstract

The intensity of tropical cyclones is sensitive to the rates at which enthalpy and momentum are transferred between sea and air in the high-wind core of the storm.

Present models of the wind dependence of these transfer rates suggest that the effective drag coefficient is more than twice the effective enthalpy transfer coefficient at wind speeds above 25 m s^{-1}.

Using this ratio in numerical models, however, makes it impossible to sustain storms of greater than marginal hurricane intensity. Some other physical process must, therefore, enhance enthalpy transfer at very high wind speeds.

This paper suggests that *re-entrant* sea spray explains this enhanced transfer.

When a spray droplet is ejected from the ocean, it remains airborne long enough to cool to a temperature below the local air temperature but not long enough to evaporate an appreciable fraction of its mass.

The spray droplet thus gives up sensible heat and returns to the sea before it has time to extract back from the atmosphere the heat necessary to continue its evaporation.

Microphysical modeling, combined with data from the Humidity Exchange over the Sea Experiment (HEXOS), makes it possible to derive an expression for the net enthalpy transfer of re-entrant spray.

This spray enthalpy flux is roughly cubic in wind speed.

When this relation is used in a numerical simulation of a hurricane, the spray more than compensates for the observed increase in the ratio of drag and enthalpy transfer coefficients with wind speed.

The momentum flux associated with sea spray is an important energy sink that moderates the effects of this spray enthalpy flux. Including a parameterization for this momentum sink along with wave drag and spray enthalpy transfer in the hurricane simulation produces results that are similar to ones based on equal transfer coefficients.