= Tropical cyclone rainfall forecasting =

Tropical cyclone rainfall forecasting involves using scientific models and other tools to predict the precipitation expected in tropical cyclones such as hurricanes and typhoons . Knowledge of tropical cyclone rainfall climatology is helpful in the determination of a tropical cyclone rainfall forecast . More rainfall falls in advance of the center of the cyclone than in its wake . The heaviest rainfall falls within its central dense overcast and eyewall . Slow moving tropical cyclones , like Hurricane Danny and Hurricane Wilma , can lead to the highest rainfall amounts due to prolonged heavy rains over a specific location . However , vertical wind shear leads to decreased rainfall amounts , as rainfall is favored downshear and slightly left of the center and the upshear side is left devoid of rainfall . The presence of hills or mountains near the coast , as is the case across much of Mexico , Haiti , the Dominican Republic , much of Central America , Madagascar , Réunion , China , and Japan act to magnify amounts on their windward side due to forced ascent causing heavy rainfall in the mountains . A strong system moving through the mid latitudes , such as a cold front , can lead to high amounts from tropical systems , occurring well in advance of its center . Movement of a tropical cyclone over cool water will also limit its rainfall potential . A combination of factors can lead to exceptionally high rainfall amounts , as was seen during Hurricane Mitch in Central America .

Use of forecast models can help determine the magnitude and pattern of the rainfall expected . Climatology and persistence models , such as r @-@ CLIPER , can create a baseline for tropical cyclone rainfall forecast skill . Simplified forecast models , such as the Kraft technique and the eight and sixteen @-@ inch rules , can create quick and simple rainfall forecasts , but come with a variety of assumptions which may not be true , such as assuming average forward motion , average storm size , and a knowledge of the rainfall observing network the tropical cyclone is moving towards . The forecast method of TRaP assumes that the rainfall structure the tropical cyclone currently has changes little over the next 24 hours . The global forecast model which shows the most skill in forecasting tropical cyclone @-@ related rainfall in the United States is the GFS (Global Forecasting System) .

= = Rainfall distribution around a tropical cyclone = =

A larger proportion of rainfall falls in advance of the center (or eye) than after the center 's passage , with the highest percentage falling in the right @-@ front quadrant . A tropical cyclone 's highest rainfall rates can lie in the right rear quadrant within a training (non @-@ moving) inflow band . Rainfall is found to be strongest in their inner core , within a degree of latitude of the center , with lesser amounts farther away from the center . Most of the rainfall in hurricanes is concentrated within its radius of gale @-@ force winds . Larger tropical cyclones have larger rain shields , which can lead to higher rainfall amounts farther from the cyclone 's center . Storms which have moved slowly , or loop , lead to the highest rainfall amounts . Riehl calculated that 33 @.@ 97 inches (863 mm) of rainfall per day can be expected within one @-@ half degree , or 35 miles (56 km) , of the center of a mature tropical cyclone . Many tropical cyclones progress at a forward motion of 10 knots , which would limit the duration of this excessive rainfall to around one @-@ quarter of a day , which would yield about 8 @.@ 50 inches (216 mm) of rainfall . This would be true over water , within 100 miles (160 km) of the coastline , and outside topographic features . As a cyclone moves farther inland and is cut off from its supply of warmth and moisture (the ocean) , rainfall amounts from tropical cyclones and their remains decrease quickly .

= = = Vertical wind shear = = =

Vertical wind shear forces the rainfall pattern around a tropical cyclone to become highly asymmetric , with most of the precipitation falling to the left and downwind of the shear vector , or downshear left . In other words , southwesterly shear forces the bulk of the rainfall north @-@ northeast of the center . If the wind shear is strong enough , the bulk of the rainfall will move away from the center leading to what is known as an exposed circulation center . When this occurs , the

potential magnitude of rainfall with the tropical cyclone will be significantly reduced .

= = = Interaction with frontal boundaries and upper level troughs = = =

As a tropical cyclone interacts with an upper @-@ level trough and the related surface front , a distinct northern area of precipitation is seen along the front ahead of the axis of the upper level trough . Surface fronts with precipitable water amounts of 1 @.@ 46 inches (37 mm) or more and upper level divergence overhead east of an upper level trough can lead to significant rainfall . This type of interaction can lead to the appearance of the heaviest rainfall falling along and to the left of the tropical cyclone track , with the precipitation streaking hundreds of miles or kilometers downwind from the tropical cyclone .

= = = Mountains = = =

Moist air forced up the slopes of coastal hills and mountain chains can lead to much heavier rainfall than in the coastal plain . This heavy rainfall can lead to landslides , which still cause significant loss of life such as seen during Hurricane Mitch in Central America , where several thousand perished .

= = Tools used in preparation of forecast = =

= = = Climatology and persistence = = =

The Hurricane Research Division of the Atlantic Oceanographic and Meteorological Laboratory created the r @-@ CLIPER (rainfall climatology and persistence) model to act as a baseline for all verification regarding tropical cyclone rainfall . The theory is , if the global forecast models cannot beat predictions based on climatology , then there is no skill in their use . There is a definite advantage to using the forecast track with r @-@ CLIPER because it could be run out 120 hours / 5 days with the forecast track of any tropical cyclone globally within a short amount of time . The short range variation which uses persistence is the Tropical Rainfall Potential technique (TRaP) technique , which uses satellite @-@ derived rainfall amounts from microwave imaging satellites and extrapolates the current rainfall configuration forward for 24 hours along the current forecast track . This technique 's main flaw is that it assumes a steady state tropical cyclone which undergoes little structural change with time , which is why it is only run forward for 24 hours into the future .

= = = Numerical weather prediction = = =

Computer models can be used to diagnose the magnitude of tropical cyclone rainfall . Since forecast models output their information on a grid , they only give a general idea as to the areal coverage of moderate to heavy rainfall . No current forecast models run at a small enough grid scale (1 km or smaller) to be able to detect the absolute maxima measured within tropical cyclones . Of the United States forecasting models , the best performing model for tropical cyclone rainfall forecasting is known as the GFS , or Global Forecasting System . The GFDL model has been shown to have a high bias concerning the magnitude of heavier core rains within tropical cyclones . Beginning in 2007 , the NCEP Hurricane @-@ WRF became available to help predict rainfall from tropical cyclones . Recent verification shows that both the European ECMWF forecast model and North American Mesoscale Model (NAM) show a low bias with heavier rainfall amounts within tropical cyclones .

= = = Kraft rule = = =

During the late 1950s , this rule of thumb came into being , developed by R. H. Kraft . It was noted

from rainfall amounts (in imperial units) reported by the first order rainfall network in the United States that the storm total rainfall fit a simple equation : 100 divided by the speed of motion in knots . This rule works , even in other countries , as long as a tropical cyclone is moving and only the first order or synoptic station network (with observations spaced about 60 miles (97 km) apart) are used to derive storm totals . Canada uses a modified version of the Kraft rule which divides the results by a factor of two , which takes into account the lower sea surface temperatures seen around Atlantic Canada and the prevalence of systems undergoing vertical wind shear at their northerly latitudes . The main problem with this rule is that the rainfall observing network is denser than either the synoptic reporting network or the first order station networks , which means the absolute maximum is likely to be underestimated . Another problem is that it does not take the size of the tropical cyclone or topography into account .