UNDERSTANDING TROPICAL CYCLONE PRECIPITATION IN THE NORTHERN PHILIPPINES

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ABSTRACT

The Philippines is exposed to Tropical Cyclones (TCs) throughout the year due to its location in the western North Pacific. While these TCs provide much-needed precipitation for the country's hydrological cycle, extreme precipitation from TCs may also cause damaging hazards such as floods and landslides. While it is known that TC behavior changes upon landfall or upon interaction with large land features, these interactions are yet to be investigated and quantified for the Philippines. This study aims to answer two main questions about the processes involved in precipitation after TC landfall. First, we intend to assess observations and determine which TC characteristics are associated with extreme precipitation. From this we create a decision table for rapid identification of extreme precipitation. Next, we evaluate the effects of the Cordillera Mountain Range's (CMR) orography on TC characteristics and TC precipitation using model simulations.

In the first part of this study, we investigate the relationship between TC extreme precipitation and TC characteristics, including movement speed, intensity, and season, for westward-moving TCs crossing Luzon, the northern region of the Philippines. We measure extreme precipitation by the Weighted Precipitation Exceedance (WPE), calculated against a 95^{th} percentile threshold, which considers both the magnitude and spatial extent of TC-related extreme precipitation. WPE has a significant, moderate positive relationship with TC intensity and a non-significant, weak negative relationship with movement speed. When TCs are classified by intensity one day before landfall (or pre-landfall), Typhoons (1-minute maximum sustained wind speed > 64 knots) tend to yield higher WPE than Non-Typhoons (< 64 knots). On the other hand, when TCs are classified by pre-landfall speed, Slow TCs (movement speed < 11.38 knots) tend to yield higher WPE than Fast TCs (movement speed > 11.38 knots). However, the relationship between pre-landfall TC intensity and WPE is more pronounced during June-September while there is no significant difference between the WPE of the Southwest Monsoon (June-September) and Northeast Monsoon (October-December) seasons. These results suggest that it is important to consider the pre-landfall cyclone movement speed, intensity, and season to anticipate extreme precipitation of incoming TCs.

We then examine the sensitivity of TC characteristics and precipitation to the CMR in Luzon, Philippines. Using the Weather Research and Forecasting (WRF) model, we simulated eight TC's with three different CMR orographic elevations: Control, Reduced, and Enhanced. We find that TC intensity weakens as early as 12 hours prior to landfall in the Enhanced case relative to Control. However, throughout the period when the TC crosses Luzon, we found no significant differences for TC movement speed and position for the different orographic elevations. When a TC makes landfall however, associated precipitation over the mountains of CMR increases as the mountain height increases. We further investigate the underpinning processes relevant to the effect of CMR by examining the effects of mountain slope, incoming perpendicular wind speed, and the moist Froude Number (F_w). Compared to

other factors, TC precipitation is best related to the strength of approaching winds multiplied by the mountain slope, i.e., stronger winds along steeper mountain slopes cause higher amounts of precipitation. Steeper slopes are expected to cause horizontal winds of TCs to uplift more quickly along the mountain, leading to more condensation in the upper levels and more rainfall on the windward side of the mountain. We also find that F_w, mountain height nor wind alone, are not good indicators of precipitation. The effects of mountain range on TC rainfall can vary with TC cases (for instance, the two north-tracking TCs had different rainfall patterns), highlighting the complexity of the mountain, wind, and rainfall relationship.

While it is critical to consider pre-landfall cyclone movement speed, intensity, and season to predict extreme precipitation from incoming TCs, the complexity of the relationships between orography, TCs, wind, and rainfall presents additional nuances to take into consideration when estimating the amount of TC precipitation and TC weakening. While the findings of this study only scratch the surface of our understanding of TCs affecting the Philippines, these can be used to fill gaps in current forecasting limitations and may help improve our response to potential hazards associated with TC rainfall.

Keywords: Tropical Cyclones, Precipitation, WRF model, Numerical Weather Prediction, IBTrACS, Orographic Effect, Cordillera Mountain Range, Luzon, Philippines