Progress in developing a statistical tropical cyclone rainfall forecast model for the Taiwan area

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Abstract

Progress of our work in developing a generalized statistical tropical cyclone (TC) rainfall forecast model for the Taiwan area based on the simple climatology and persistence (CLIPER) model is reported in this paper. A regression model is setup to first verify the relative weighting of climatology and persistence currently in use in CLIPER. For preliminary test, the regression is performed for the 22 traditional rain stations individually. A typical result is that the weighting for climatology increases in the first few hours of forecasts and then stabilizes afterward to a value about 0.7-0.8. Comparatively, the coefficient for persistence usually starts from a higher value but its importance decreases gradually, in consistence with our previous combination of climatology and persistence in CLIPER. If the regression results for each station are examined more closely, it can be found that stations located in different regions possess different characteristics. It is generally recognized from these regression results that different combination of climatology and persistence may be necessary for different forecast times, and different regions in Taiwan. Future work includes addition of TC structure parameters, topography parameters, environmental parameters and possibly remote-sensing data to the regression model.

Keyword: Typhoon rainfall, climatology-persistence model, generalized linear regression

1. Introduction

Lee et al. (2006) and Cheung et al. (2006) described the design and establishment of the necessary rainfall database, and the setup of a simple climatology-persistence (CLIPER) tropical cyclone (TC) rainfall model that has been utilized in the National Center for Disaster Reduction (NCDR) in the past few years for rainfall estimation and downstream applications such as calculations of flood and debris flow potential during TC periods. Objective verification of the model was performed based on several skill measures. For example, using the model database that consists of typhoon cases in 1989–2002, correlation coefficient (*R*) between CLIPER's forecasts (using the official forecast tracks from the Central Weather Bureau) and observations at all the 365 automatic rain gauges ranges from 0.63 for 3-h accumulated rainfall to 0.5 for 24-h period. The verification for the independent cases in 2003-2004 actually indicated slightly higher correlation coefficient in the short range (0.77 for 3-h and 0.68 for 6-h forecasts). Moreover, the CLIPER model rainfall database has recently been extended to 1989–2004. The correlation between model estimates and observations for typhoon cases in 2005 and 2006 was either similar to that using the old database or increases slightly, indicating that the updated database is quite adequate in describing typhoon-related rainfall climatology.

The characteristics of the model was further explored by stratification of the skill measures according to some related physical parameters including the TC track type, size of the TC and height of the rainfall stations. For example, the equitable threat score (ETS) was higher for TCs with an east-west oriented track and larger size (more precisely speaking, radius of 30-kt wind R_{30} > 200 km). In addition, ETS obtained by rain stations in plain areas was on average higher than those in the mountainous areas, indicating strong influence from topography (Lin et al. 2002).

2. Optimized combination of climatology and persistence

According to these verification results, the strategy of formulation of a more generalized statistical rainfall model based on several linear regression techniques was discussed in Cheung et al (2006). It can be seen that CLIPER may be further improved if the model is able to take into account TC track type, structure (intensity, size, etc) and topography of Taiwan. Therefore, a more generalized statistical model is to be setup based on the current CLIPER, which has the regression form

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon,$$

where y can be treated as the rainfall at a particular station, x_i's the predictors, β's the regression coefficients and ε the error term.

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As a starting point in this model development, a regression model is setup to first verify the relative weighting of climatology and persistence currently in use in CLIPER. The regression model can be written as

$$ppn = \alpha(\text{climatology}) + \beta(\text{persistence}) + \gamma,$$

where ppn is hourly rain rate up to a lead time of 24 h from the initial time, persistence is still the average rain rate in the 3-h period before initial time, and γ acts as the residual in the model. The regression is performed for the 22 traditional rain stations individually (Fig. 1). A typical result is that the weighting for climatology (coefficient α) increases in the first few hours of forecasts and then stabilizes afterward to a value about 0.7-0.8 (Fig. 2). Comparatively, the coefficient for persistence usually starts from a higher value but its importance decreases gradually, in consistence with our previous combination of climatology and persistence in CLIPER. The residual term γ is usually small compared with the other two terms (coefficient times rain rate).

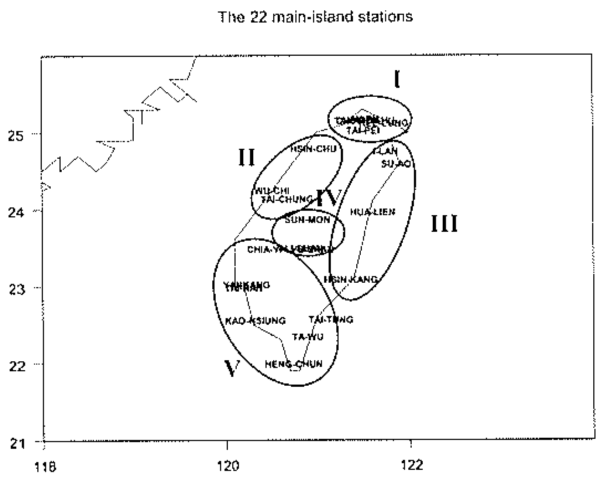

Fig. 1 Rain stations for which regression model is established.

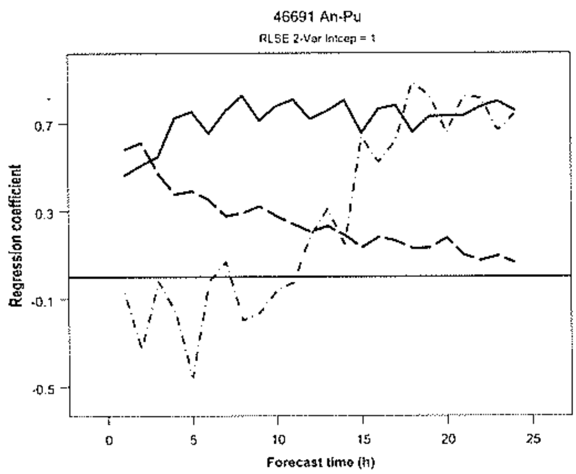

Fig. 2 Time series of the α, β and γ regression coefficients for station An-Pu.

If the regression results for each station are examined more closely, it can be found that stations located in the four large regions (Fig. 1) possess different characteristics. For the stations in region I (north region), the contribution from persistence usually drops quit slowly (Fig. 3), meaning that the effectiveness of persistence may be extends beyond 6 h. However, in region II (northwest region) the value of β is low, indicating that climatology usually dominates in this region (Fig. 4). For the other three regions, the relative contribution from climatology and persistence is similar to the rest of the stations, and the actual values of the coefficients vary from station to station. It is generally recognized from these regression results that different combination of climatology and persistence may be necessary for different forecast times, and different regions in Taiwan.

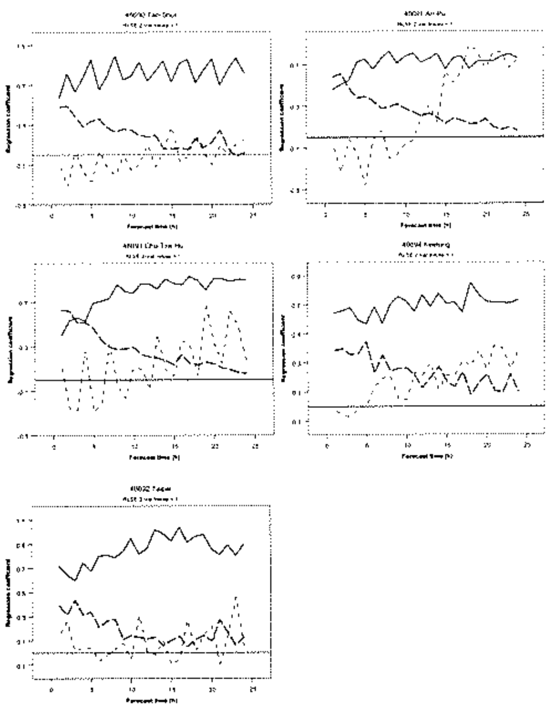

Fig. 3 As in Fig. 2 except for stations in region I.

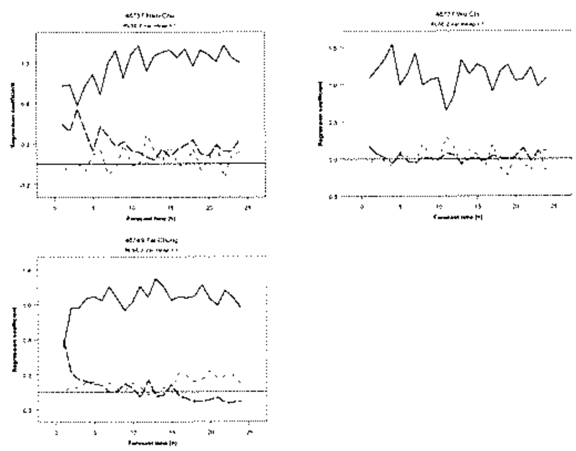

Fig. 4 As in Fig. 2 except for station in region II.

3. Environmental effects

As discussed in Lee et al. (2005) for the case of Typhoon Mindulle (2004), rainfall pattern under the influence of monsoonal southwesterly flow deviates much from usuall TC rain climatology and is difficult to forecast. Another TC case with similar situation is Typhoon Bilis (2006). On 14 July, the center of Bilis had passed through northern Taiwan and entered the Taiwan Strait. However, mesoscale systems with strong convection were embedded in southwesterly flow that persisted in the South China Sea and brought a total rain of over 600 mm in some of the southwestern Taiwan regions (Fig. 5). However, this rain distribution is rare in TC rain climatology and thus CLIPER's estimate of total rain does not resemble observation well (correlation coefficient is only 0.28). As a matter of fact, if the period of rain associated with southwesterly flow is eliminated, correlation of CLIPER forecast with observation increases to 0.66.

Another important factor that affects the amount of rain brought by typhoons and that associated with monsoonal flow is its moisture content, which may be inferred by some of the satellite and radar remote-sensing data. Therefore, a future research effort will be to include some synoptic parameters (e.g., wind speed in a certain region with respect to the TC) to take into account potential influence from the monsoonal environment to the rainfall pattern, and remote-sensing rain rate estimate when a typhoon is approaching Taiwan to consider different moisture content associated with different typhoons.

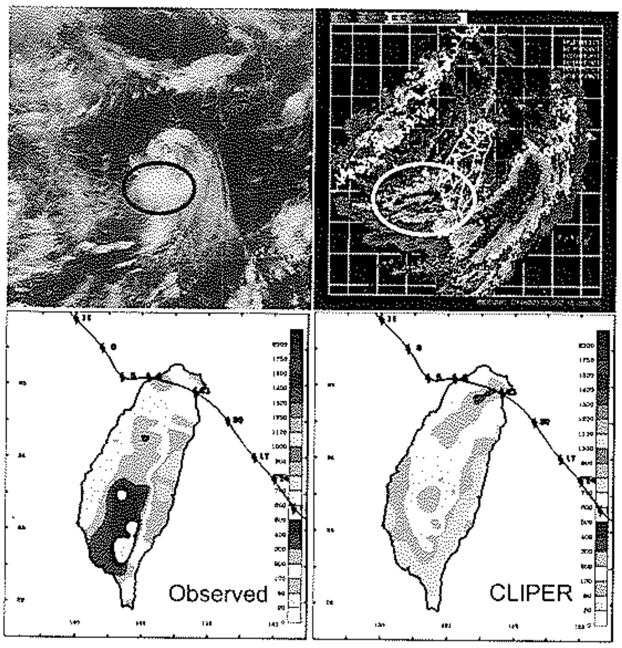

Fig. 5 (Upper left) Infrared satellite imagery at 0930 UTC 14 July 2006, (upper right) CWB radar reflectivity at 0500 UTC 14 July 2006, (lower left) total observed rain for Typhoon Bilis, and (lower right) CLIPER forecast for the same period.

4. Further issues in model development

Certainly, a statistical model with all of the predictors mentioned above can be implemented for operational application. However, not all these parameters have equal contribution to the skill of the model, and several statistical techniques can be used to select the most significant factors. These include forward or backward stepwise regression, and the more sophisticated projection pursuit regression. With selection of the most important parameters for forecasting rainfall, insight can also be obtained of the essential physical processes that are responsible for determining the rainfall distribution.

In addition, a generalized form of linear regression can be used to consider "interaction" effects among the predictors (Johnson and Wichern 1992). For example, the combined effect of a particular typhoon track type and month of occurrence can be isolated, or that the effect of TC size and topography can be considered together. The latest progress along this line of research and verification of our new statistical model will be reported in a later paper.

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