RADAR EXTRAPOLATION IN VERY SHORT-RANGE RAINFALL FORECASTING IN HO CHI MINH CITY

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Abstract: *This article presents the study results of TITAN and SWIRLS tools for extrapolating radar data to forecast rainfall (1 - 6 hours) in Ho Chi Minh City region. The SWIRLS and TITAN are optional tools to extrapolate radar data. The validation results implemented by comparing with GSMAP data (gridded rainfall data) and observation measured at 219 stations at Southern Viet Nam (SVN). The study results show that TITAN and SWIRLS tools can forecast well the place n, direction and speed of rain as well as place of thunderstorm. Especially, the error index calculations showed the better results in SWIRLS than TITAN. However, the better moving trend forecast in the case of Typhoon Usagi is found by TITAN than by SWIRLS.*

Keywords: *Short-range rainfall forecast, TITAN, SWIRLS, Extrapolation, WRF.*

1. Introduction

In Ho Chi Minh City (HCMC), heavy rain is the major phenomena causing the most serious consequences. Heavy rainfall in HCMC has a highly unexpected characteristic, occasional with violent rain (huge amount in a very short time), particularly when combined withhigh tide to cause local flooding. In recent years, the increase rate of frequency and intensity of un-normal heavy rainfall events are found year by year. Therefore, it is essential to carry out research on improving in extreme heavy rainfall forecasts in HCMC. Currently, the short-range forecast of heavy rainfall in HCMC is still facing many limitations: The use and exploitation of products from weather radar are mainly based on currentand past radio -response images to make subjective forecasts for the future; the limitations of numerical models in short-term heavy rainfall forecasting (initial conditions, physics parameterizations...); limited experience in data assimilation, monitoring data quality; limited facilities (HPC system, software etc.).

In recent years, radar has been being an important equipment in real-time monitoring and forecasting dangerous weather phenomena such as thunderstorms, storms and heavy rain, etc. The advantage of radar is found by providing a large amount of data from surface to altitude levels with a very high spatial and temporal resolution. Currently, there are many methods that suggested in extrapolating radar data for extreme short-term heavy rainfall forecast (1 - 6 hours) over in the world. SWIRLS originally focuses on thunderstorms and forecasting the storm's path, and the system is still being developed and used very effective [1]. The Japan Meteorological Agency (JMA) has been using radar data are in extrapolating extreme rainfall short-range forecasts. In the term of the extrapolation process, the development and weakening of the rain system due to the impacts of terrain are also considered. The results show that extrapolated forecasting is more skilled than numerical modeling, but it decreases skills faster over time, so to be more optimal, they apply a combination method between the

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extrapolated results of the radar and the numerical model [9]. In Vietnam, there have not been many studies on extrapolating radar data, most recently there has been a study by Cong Thanh and his colleagues who applied Titan software to identify, track, and analyze instantly for thunderstorms in HCMC region. This study has compared the maximum response of CMAX from extrapolation with reality; but has not compared the quantitative rain results of extrapolation and observation [3]. In general, there are many limitations in using tools for extrapolating radar data to improve issues of heavy rainfall in Vietnam. In addition, applications in optimizing results and adjusting tools for a very small region in Vietnam are still very complex and long-term issues, requiring more in-depth studies. Therefore, the purpose of this study is to investigate in applying TITAN and SWIRLS tools to improve short-range rainfall forecast in HCMC based on extrapolating radar data.

1.1. The short-range warning of intense rainstorm in localized systems

SWIRLS (Short-range Warning of Intense Rainstorm in Localized Systems) is an instantaneous precipitation forecasting system developed by the Hong Kong Observatory (HKO) since 1997. The SWIRLS prototype was put to the test during the rainy season in 1998. This test is considered an initial success for the quantitative forecast of rainfall in a few hours. After some minor modifications based on user logs, the SWIRLS system was officially operated in April 1999. Advanced techniques are deployed in SWIRLS to analyze and predict precipitation and convective weather phenomena over the next few hours. SWIRLS is also deployed in various meteorological services or participates in international forecasting projects to support research and development of rainstorm broadcast techniques. The community version of SWIRLS, or com-SWIRLS, was developed to facilitate knowledge exchange and collaborative development of rain broadcast techniques [2]. The main development goal in SWIRLS is to use both radar and rain gauge data to monitor and predict trends in local precipitation distribution over a few hours. The reanalyzed dataset, based on time-adjusted reflectance precipitation relationships, has proven to be extremely useful in providing real-time precipitation information to forecasters as well. as providing information for the physical process in weather forecasting [1]. Some basic features of SWIRLS are: Quantitative precipitation estimation (QPE) based on radar data, rain gauge or a combination of both; Monitoring storm movements; Extrapolating data using semi-Lagrangian diagram up to 6 - 9 h ahead.

1.2. Thunderstorm Identification, Tracking, Analysis and Nowcasting (TITAN)

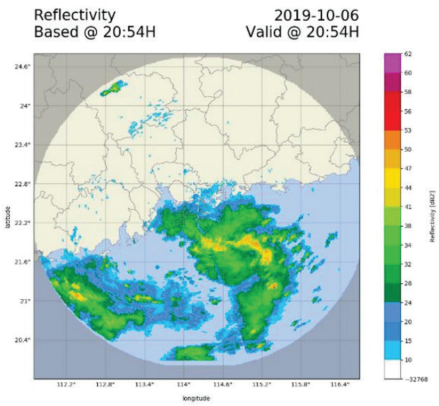
TITAN (Thunderstorm Identification, Tracking, Analysis and Nowcasting) is a software that can identify, track, analyze and forecast extremely short thunderstorms and rain from weather radar data, built-in 1990 by M. Dixon and G. Wiener. Model TITAN is constantly developed and perfected by many researchers from NCAR and UCAR (USA) From 1990 - 1992 TITAN was tested on the prototype NEXRAD radar in Denver, Colorado [4]. TITAN uses random methods based on mass tomography data of the thunderstorm and weighted linear extrapolation from the historical dataset to determine the growth of the thunderstorm in the next hours [3]. TITAN can identify, monitor, analyze and forecast extremely short thunderstorms and rain from weather radar data, with main features: Operating in two modes: real-time and historical; Extrapolating of radar data, time step up to 10 minutes; Supporting extrapolation of radar data 10, 20, 30, 40, 50, 60 minutes; Supporting 1, 3, 6, 12, 24 hours cumulative rain forecast; Running multiple radars at the same time; Supporting to export a variety of output formats (xml, mdv, ASCII); and supporting input data quality check.

TITAN software uses a semi-Lagrangian extrapolation diagram with basic functions: Using interpolation of neighboring points to determine cloud drives based on radar response, and at the same time analyzing basic properties of the cloud do the top condition; Forecasting the displacement of the cloud drive based on linear extrapolation. Based on the predictive information of the responsiveness of the cloud drive, the size of the cloud drive can predict the water content, rainfall intensity and total rainfall accumulated over time by the relationship between the responsiveness Z and the amount of rain R (ZR relationship).

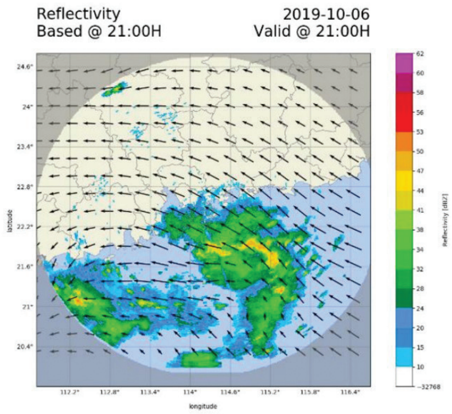
2. Methodology and data

2.1. Radar extrapolation algorithm

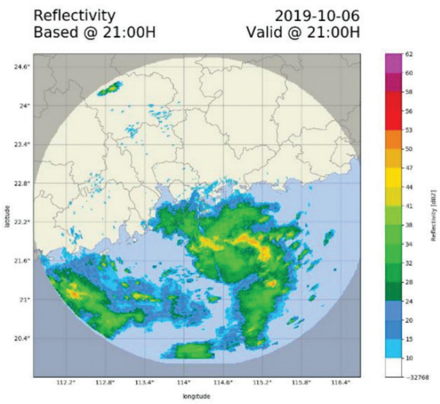
Step 1: Determine the TREC vector field: Extremely short-term forecasting is based on radar data with a high update time (5 - 10 minutes) to identify areas of deep convection and clouds with a high probability of precipitation and to estimate displacement(using consecutive data over time using the maximum correlation method for the TREC responsiveness - Tracking Radar Echoes by Correlation) (Figure 1).



a 6-minutes reflectivity ago



Field of motion (u,v component)

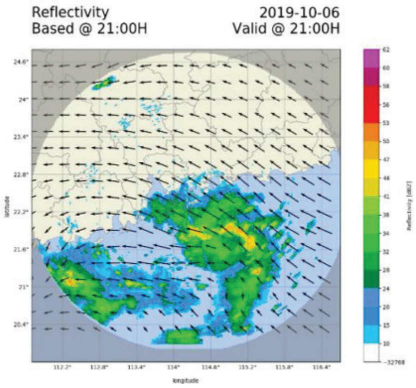


present reflectivity

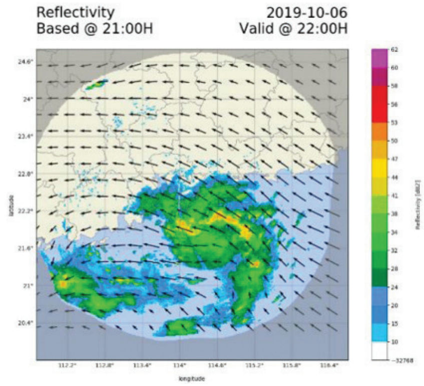
Figure 1. Illustrate the process of determining the TREC vector field

Step 2: Handling deviation vectors: The vector field is then filtered, and the deviation vectors are replaced with the mean of the surrounding vectors.

Step 3: Extrapolation of radar data: After building the direction field and the displacement speed of the convective drives capability of causing rain, thunderstorms will apply the Lagrangian method to extrapolate the satellite response or radiation over time to determine the region short term effects (Figure 2).



Reflectivity and wind vector



Extrapolate

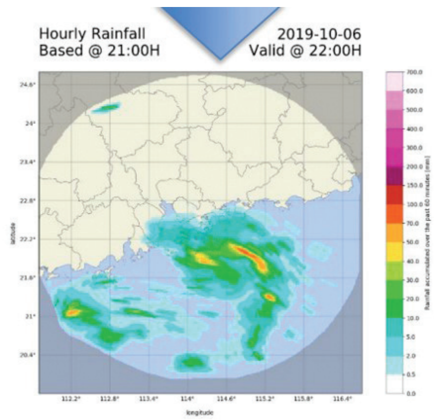


Figure 2. Illustrate the process of extrapolating radar data and converting it to rain

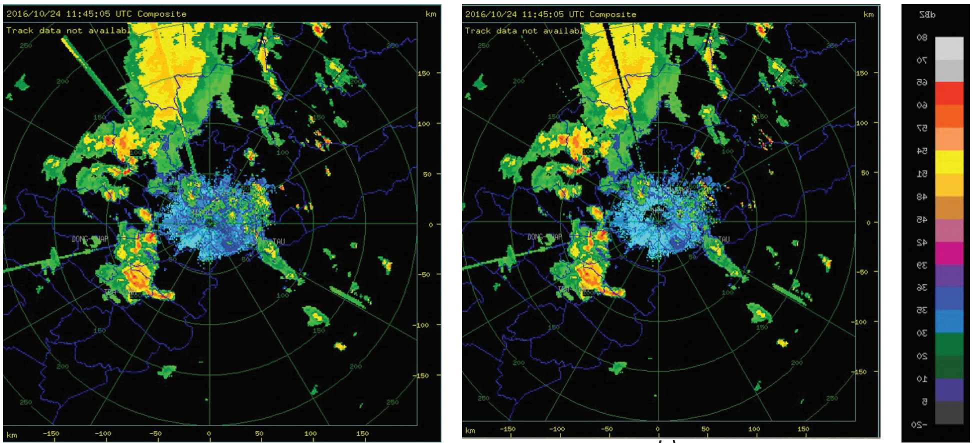
Step 4: Converting reflectivity to rainfall: In the SWIRLS software, the Z-R relationship is adjusted in real-time. This is done by comparing every 5 minutes the reflectivity of the radar with the rainfall at the monitoring station. However, it can also be determined by fixed formulas. After obtaining the radar response monitoring, using the experimental relationship based on the observed response from radar and the rain speed of Marshall-Palmer, we can estimate the rain intensity R (mm/h) from the radio response of the radar target Z ($mm6/m^3$) is as follows: $Z = AR^B$ where A, B are experimental parameters, typical values are A = 200 and B = 1.6. Using the relationship between Z' = 10 lgZ and Z' (dBZ) as the radar response, we have the equation for the rainfall intensity estimate as follows: $R = C10^{DZ}$. The above relationship is usually found with high reliability, a sample set of response and rain data observed over many months or years is needed. In this topic, we have used the formula that proposed by Nguyen Huong Dien [7]. This formula has been studied with good error for the Southern Vietnam region.

2.2. Handling radar data

In this study, the Nha Be radar (10°39'31" N; 106°43'42" E) date were used with some main technical parameters such as operating frequency: 5500 - 5700 MHz (C wave); antenna blade width: ≤ 1.0°; monitoring radius: 30, 60, 120, 240, 480 m; doppler wind observation radius: 30, 60, 120 km. This radar device has been effective in tracking and monitoring weather phenomena within a radius of about 480 km; warn and forecast dangerous weather phenomena such as storms, tropical depressions, thunderstorms, etc. within a radius of about 240 km; and the phenomenon of rain, heavy rain, etc. within a radius of about 120 km around Ho Chi Minh City. It should also be noted that for Nha Be Radar with a scanning radius greater than 120 km, radial wind speed data should not be used for assimilation because at this time the radial wind will not be good. As mentioned above, the problem of processing radar data before entering assimilation is one of the important steps, it directly affects the results of 3dvar simulation even if there is too much poor data. It can corrupt the analysis from 3dvar, there are many methods studied to get the best data before it is included in the model.

Regarding quality control, many studies have compared the results of no quality control (QC) and with QC, the results show that no QC can cause 3dvar to fail to converge or create an analytic field, but bad data propagates to regions other good data and as a result, the original analysis field may deteriorate [8].

For the raw data of Nha Be, there will usually be ground clutter, sea clutter, side beam effects and wind field overlapping noise, therefore, quality testing is necessary [Figure 3].



a) b)

Figure 3. The illustration of non-quality control and quality control for radar data

2.3. Experiment design

To perform the forecast for the next 6 hours, we use 6 radar data files every 10 minutes (for SWIRLS) and all previous 1 - 3 h radar files (for TITAN). Radar data, before being extrapolated, will go through a quality control step before being added to the extrapolation program (TITAN or SWIRLS). The software will automatically extrapolate the response and then convert it to the corresponding rainfall (Figure 4). In operation the program is run continuously once every hour, providing forecasts and warnings when there is a risk of heavy rain (Figure 5). In this paper, the extrapolation was continuously operated in the cycle from 10:00 am on November 24, 2018 to 9:00 pm on the same day, each extrapolating 1 hour apart and forecasting for the next 6 hours.

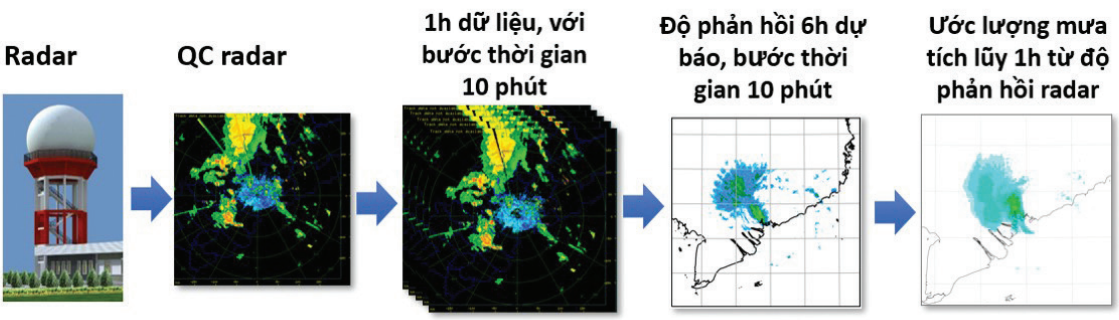


Figure 4. Process of extrapolating radar data

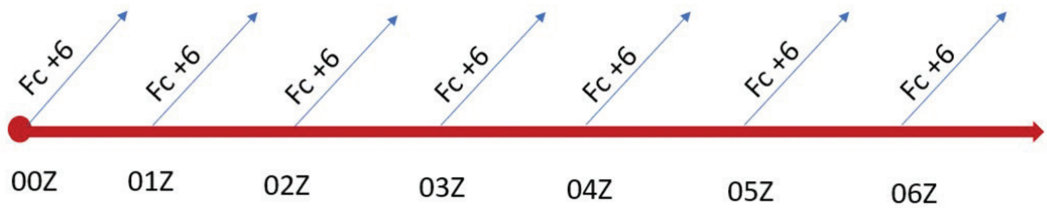


Figure 5. Extrapolation of radar data in real time mode

Data: Monitoring data for simulation evaluation includes rain data of 219 stations around HCMC (Figure 6); Radar data is taken from Nha Be Radar including feedback and radial wind taken every 10 minutes on November 25, 2018; the radar scans 5 - 8 elevation angles and a radius of 120 km during this time.

Evaluation method on station: Using 3 statistical indicators: mean absolute error (MAE), root mean squared error (RMSE) and relative error (RE).

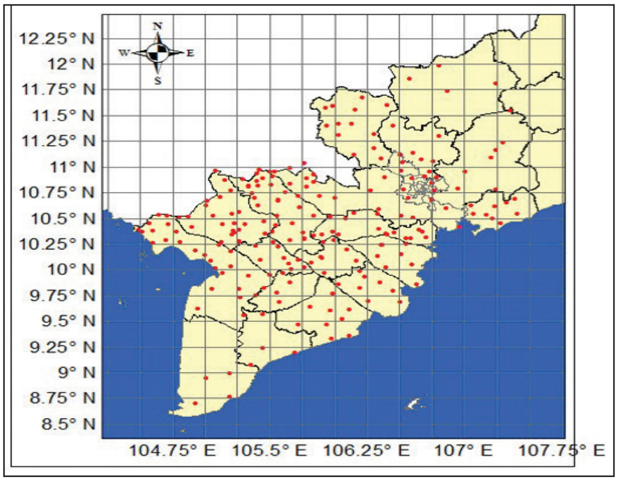


Figure 6. Location of observation stations (red dot)

$$MAE = \frac{1}{n}\sum_{I=1}^{n}|FI - OI| \ ; \qquad RMSE = \sqrt{\frac{1}{n}\sum_{I=1}^{n}(FI - OI)^2}$$

FI is the forecast value, *OI* is the observed value, *N* is the sample volume

3. Results

3.1. Extrapolation results of radar data

In this section, the simulation results is presented on the grid of SWIRLS, TITAN and compare with the data from GSMAP for the period from 11 - 14 UTC on November 24, 2018.

Figure 7 is the result of extrapolated rainfall accumulated hourly (shaded figure), output from TITAN software, in which the red contour lines are TITAN's forecast for each thunderstorm and the trend of movement and development them in the following hours. Comparing this result with the actual results from GSMAP data (Figure 9) shows that the TITAN software can capture relatively well the location of heavy rain areas and the movement trend of the USAGI storm (which is gradually entering Ho Chi Minh City). In the period from 11 to 14 UTC on November 24, 2018 this storm tends to move closer to the mainland, making the rainfall in HCMC area increase, the number of thunderstorms in this area also increases and develops more strongly. TITAN software has captured this trend quite well. However, closely monitoring the rain images (after being converted from reflectivity) can see a clear demarcation within the radius from 100 km onwards from the center of the radar (this does not seem to be reasonable because the rain area must be seamless). In terms of quantitative forecast results, it can be seen that TITAN gives a much higher rainfall than GSMAP. (Although GSMAP is only a reference channel in terms of area, rainfall from this observation is still not good in many cases).

Figure 8 is the extrapolated result from SWIRLS software. About the tendency of rain to grow stronger, it seems that this software can only catch it in the first 1 hour (at 11 UTC). In the next hours (13 - 14 UTC) rainfall in HCMC area does not increase but even decreases. The software also fails to capture the USAGI storm's tendency to move closer to land. It seems that because SWIRLS only uses simple linear extrapolation, it does not capture as well as TITAN. In terms of rainfall, SWIRLS gives a better forecast of rainfall than TITAN (when compared to GSMAP).

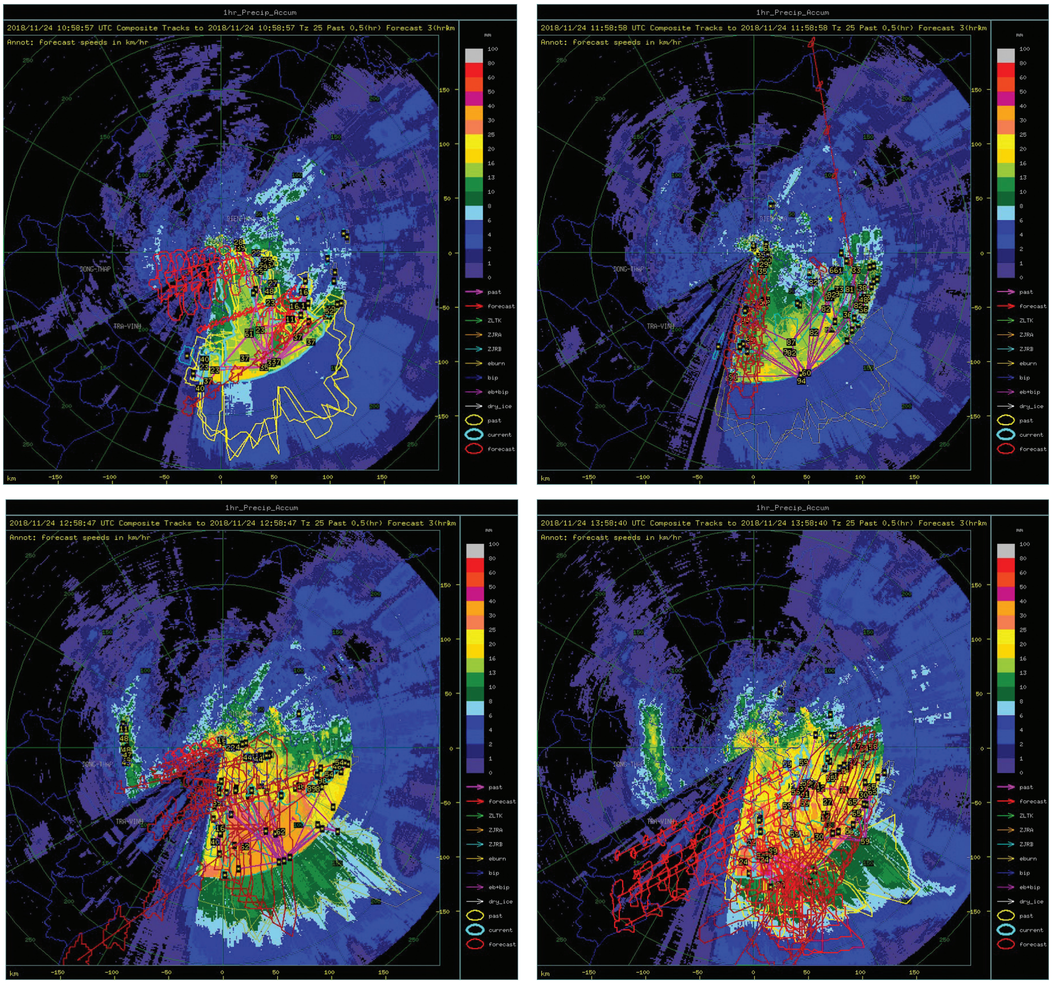


Figure 7. 1 hour cumulative rainfall extrapolated from TITAN software from 11 - 14 UTC on November 24, 2018

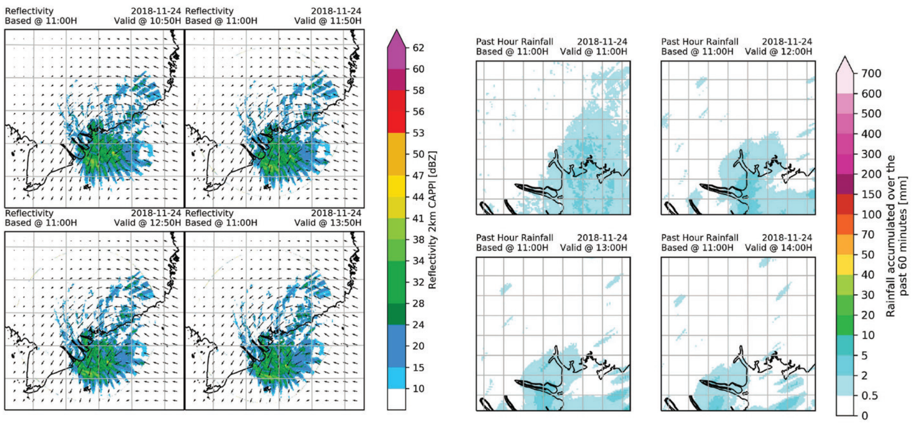


Figure 8. Responsiveness (left) and cumulative precipitation (right) extrapolated from SWIRLs software from 11 - 14 UTC on November 11, 2018

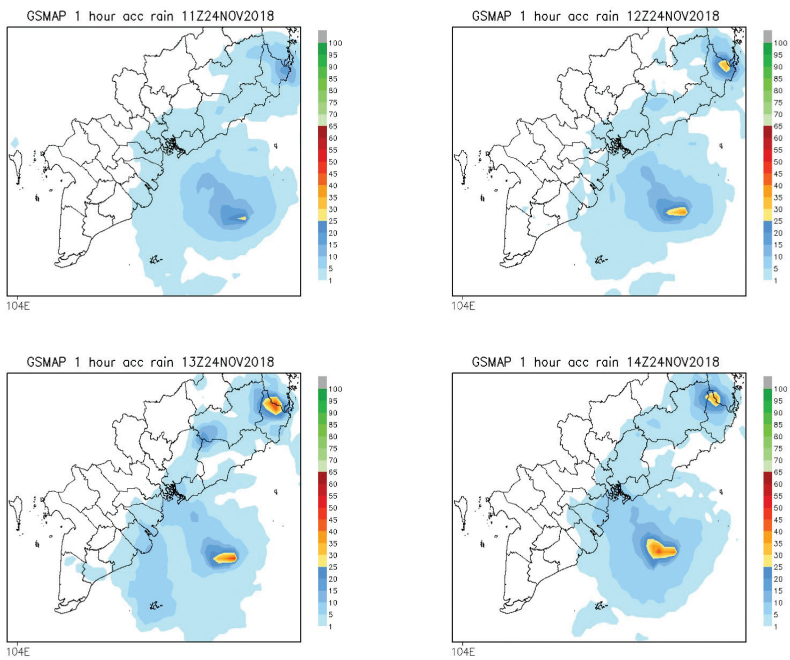
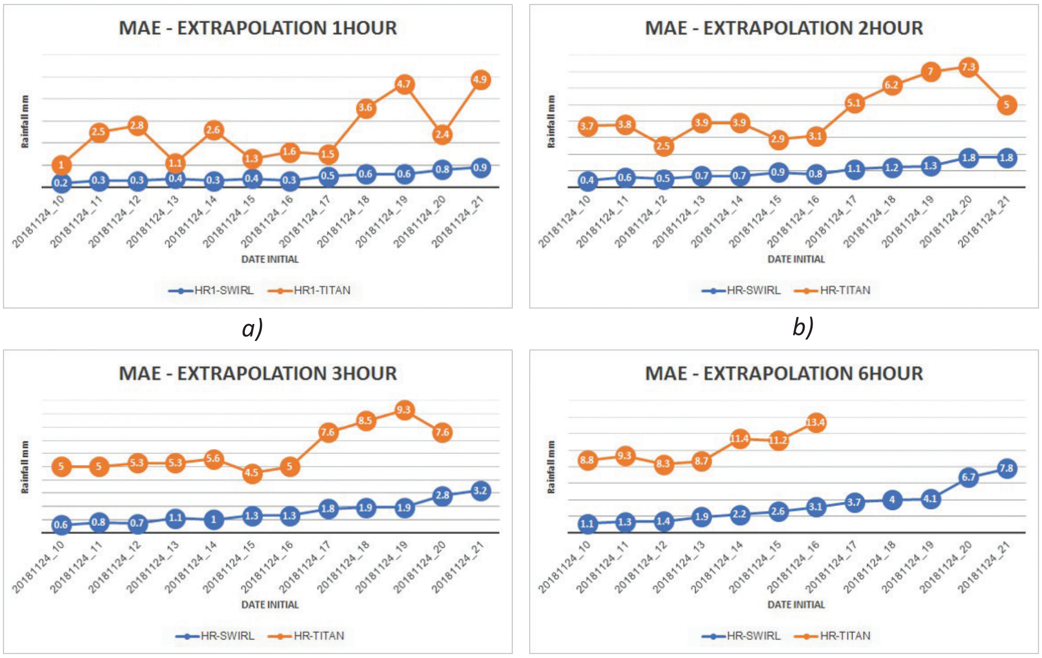


Figure 9. GSMAP data from 11 - 14 UTC on November 24, 2018

3.2. Assess error

The error assessment is based on monitoring data from 219 stations in the Southern region and extrapolated rain data extracted to the corresponding station points for panels from 10 UTC to 21 UTC on November 24, 2018.

Figure 10 is the result of MAE error assessment for each forecast from 10 UTC to 21 UTC on November 24, 2018 with 4 different forecast periods: 1 h - Figure 10a; 2 h - Figure 10b; 3 h - Figure 10c and 6 h - Figure 10d. With the 1h forecast period, the error of MAE of SWIRLS is quite small at about 0.2 - 0.9, of TITAN is 1 - 4.9. With the 2 h forecast period, the error of MAE of SWIRLS is 0.4 - 1.8, TITAN is 2.5 - 7.3. At the 6 h forecast period, the error of SWIRLS is from 1.1 to 7.8 but that of TITAN is very large from 8.8 to 14.3. Thus, when the forecast period increases, the errors of both software show that the errors also increase gradually (this is quite reasonable compared to previous studies). In general, the results show that the error of SWIRLs is much smaller than that of TITAN at all 4 forecast periods from 1, 2, 3 and 6 hours.



a) b) c) d)

Figure 10. Results of error assessment, comparison between TITAN and SWIRls

4. Conclusion

This article has studied the application of two software TITAN and SWIRLS to extrapolate radar data for Ho Chi Minh City on November 24, 2018 to provide initial comparisons between these two types of software. The results show that, in terms of area, TITAN software seems to be a better predictor of SWIRL when compared to GSMAP (following the maps Figure 7 - 8 for the forecast period from 1 - 6 h). However, in terms of rainfall, especially when comparing and evaluating the MAE error with 219 stations in the Southern region, the SWIRLS software gives a significantly smaller error.

The study also shows that the error of each tool is quite small in the forecasting term from 1 to 3 h, the error of MAE of SWIRLS is about 0.2 - 0.9, that of TITAN is 1 - 4.9, but at larger forecast periods, the error increases very quickly, so it is recommended that it is not possible to use forecasting periods larger than 3 hours, or it is possible to combine this software with a numerical model. Subjectively, SWIRL software is relatively linear, while TITAN uses more complex algorithms.

This is the test result for one case and about 10 more extrapolations for each software. In order to continue the application and improve the forecast quality, it is necessary to have many tests on a large sample set, which is divided into many cases and combined with corrections compared to actual observations.

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