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A STUDY ON THE ROLE OF RAPID RADAR DATA ASSIMILATION USING WRF MODEL FOR VERY SHORT-RANGE QUANTITATIVE PRECIPITATION FORECASTING FOR HO CHI MINH CITY AREA

PHD THESIS SUMMARY ON METEOROLOGY AND CLIMATOLOGY

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LIST OF PUBLICATIONS

1. **Truong Ba Kien**, Pham Thi Thanh Nga, Tran Duy Thuc, Phung Thi My Linh, Vu Van Thang: Verification of quantitative rainfall forecast over Vietnam by using the weather research and forecasting model, Vietnam Journal of Hydro-Meterology 2022, 738, 1-11.
2. Thang Vu Van, Thang Nguyen Van, Khiem Mai Van, Tien Du Duc, **Kien Truong Ba**, Thuc Tran Duy, Hung Mai Khanh and Lars Robert Hole, 2022, Assessment of heavy rainfall forecasts over the southern Vietnam by using WRF-ARW with different physical parameterization schemes, Disaster Advances Journal.
3. **Truong Ba Kien**, Vu Van Thang, Tran Duy Thuc, Pham Xuan Quan, Nguyen Quang Trung, 2020: Constructing Rapid Refresh system for rainfall nowcasting (0-6h) at Ho Chi Minh city, VNU Journal of Science: Earth and Environmental Sciences, ISSN 2588-1094, Vol. 37, No. 4, 2021
4. **Truong Ba Kiên**, Tran Duy Thuc La Thi Tuyet: An investigation into the causes of the the heavy rainfall affecting Ho Chi Minh city from 24th to 26 th October 016. Journal of climate change sciences No. 13-3/2020
5. **Truong Ba Kien**, Tran Duy Thuc, Nguyen Quang Trung, Nguyen Binh Phong,Vu Van Thang: The ra-đa extrapolation for very short-range forecasting of rainfall at Ho Chi Minh city, 2021. JOURNAL OF CLIMATE CHANGE SCIENCE, NO. 19 - SEP. 2021

1.Introduction

Necessity of the chosen thesis topic “A study on the role of rapid radar data assimilation using WRF model for very short-range quantitative precipitation forecasting for Ho Chi Minh City area."

Currently, the problem of quantitative precipitation forecasting, especially extremely short-term quantitative rain, is still a big challenge for operational and professional forecasting agencies in the world as well as in Vietnam. Ho Chi Minh City is a dynamic economic city that is developing very fast with a rapid urbanization rate, an economic capital for the whole country, however, the infrastructure has not been able to keep up with this development.

Currently, the weather radar network in Vietnam is increasingly being completed with a network of 10 upgraded radar stations covering the entire territory. Specifically, the Nha Be radar station has been recently upgraded as well as innovation of assimilation technology that helps in serving hourly update data assimilation in the WRF model to predict the very short-range of quantitative rainfall forecasting for small areas. Therefore, it is expected that this thesis will study " ***A study on the role of rapid radar data assimilation using WRF model for very short-range quantitative precipitation forecasting for Ho Chi Minh City area*** " with the main goal is to improve the accuracy of very short-range of quantitative rainfall forecasting for the Ho Chi Minh City area based on rapidly updated assimilating radar data for the WRF model.

2. Research objectives

1) Determine the optimal set of parameters for quickly updating radar data for the WRF model in the city area. Ho Chi Minh City (called

HCM-RAP) in improving the quality of extremely short-term quantitative rain forecasts (1-6 hours) for the city area Ho Chi Minh.

2) Improve extremely short-term rain forecasting skills and determine the specific contribution of feedback and radial wind speed in improving the quality of quantitative rain forecasts for 1 - 6h forecasts and Different rainfall thresholds for the city area Ho Chi Minh, based on rapid assimilation of radar data for the WRF model.

3. Research questions

The thesis focuses on answering the following Research questions:

1) How will the assimilation of rapidly updated radar data for the WRF model affect the forecast of very short-range rainfall (1-6 hours) for small areas?

2) Which physical configuration combination is most optimal for the HCM-RAP model in improving the very short-range quantitative precipitation forecasting skills (1-6h) for the Ho Chi Minh City area?

3) What is the contribution and role of reflectivity and radial velocity when assimilating and rapidly updating radar data to the skill of very short-range quantitative precipitation forecasting with different precipitation thresholds?

4) Can rapidly updated radar data assimilation for the WRF model improve accuracy compared to radar extrapolation for the Ho Chi Minh City area?

4. Defending points

1) The rapidly updated radar data asssimilation for the WRF model will improve the very short-range quantitative precipitation forecasting skill for 1-6h leadtime for the Ho Chi Minhcity area compared to currently forecasting.

2) The radar reflectivity plays a dominant role and contributes much more significantly than radar radial velocity in improving rainfall forecast for 1-6h leadtime at different thresholds.

5. Subjects and scopes of research

Research objects: Apply the rapidly updated radar data assimilation method to improve very short-range quantitative precipitation forecasting for the Ho Chi Minh City area.

Scope of research: Heavy rainfall events in years of 2019, 2020 and 2021 in the Ho Chi Minh city area.

6. Research methods and techniques

Numerical prediction model method: Using the WRF-DA model with rapidly update radar assimilation mode to re-forecast very short-range quantitative precipitation forecasting for selected-aboved heavy rainfall events in the Ho Chi Minh and ambient areas.

Statistical method: Used to calculate, compare, and evaluate rainfall forecasting skills.

7. New contributions

1) The thesis has tested and determined a suitable set of physical parameters for the HCM-RAP system to be applied in quantitative forecasting of very short-range quantitative precipitation (1-6 hours) for the Ho Chi Minh City area. According to the assimilation method, the radar is quickly updated hourly for the WRF model

2) The thesis has analyzed and evaluated the effectiveness of observed elements of radar in rapidly updated assimilation. It shows that reflectivity has the biggest influence in improving the skill of very short-range quantitative precipitation forecasting in compared to non-assimilating. The quantitative forecast of 4-6 hours leadtime indicated that it is better in comparison to radar extrapolation, solving the aboved gaps and in association with radar extrapolation of 1-3 hours ahead to improve the quality of very short-range quantitative precipitation forecasting for Ho Chi Minh City area.

8. Scientific and practical contributions

a) Scientific contributions

The research results of the thesis have contributed to confirming that the radar reflectivity plays a dominant role and contributes much more significantly than radar radial velocity in improving rainfall forecast. Improving the quality forecasts in the 4-6 hours leadtime in comparison to radar extrapolation, it will solve the aboved gaps and in association with radar extrapolation of 1-3 hours ahead to improve the quality of very short-range quantitative precipitation forecasting for the Ho Chi Minh City area.

b) Practical contributions

The current of equipment, technology, data and especially the current computing resources capacity at the National Center for Hydrometeorological Forecasting and the Southern Hydrometeorological Station, the HCM-RAP system can be served in operational forecasting that will provide reference results in the very short-range quantitative precipitation forecasting for the Ho Chi Minh City area.

CHAPTER 1: LITERATURE REVIEW OF DATA ASSOCIATION IN ULTRA SHORT-TERM QUANTITATIVE RAIN FORECAST

To improve the quality of quantitative rainfall forecasts of numerical models, meteorological researchers and national forecasting agencies have been focusing on the following five main *directions:* ***(1)*** *Research to increase the intensity grid resolution for the model* to be able to directly calculate small-scale physical processes (less than a few kilometers). Along with the development of computational science as well as the ability to develop high-order turbulence diagrams, many studies have applied high-resolution numerical models to quantitatively forecast rainfall; ***(2)*** *Research to improve/select physical parameter schemes* to suit the properties and thermodynamic conditions of the research area; ***(3)*** *Research and apply data assimilation methods* to update Nonconventional Data sources such as radar, satellite, and automatic rain-gaugse data to improve initial conditions. ***(4)*** *Research and apply statistical bias-correction methods to correct* systematic errors of the model based on the actual observations in the past. ***(5)*** *Research and apply ensemble forecastings* to provide additional probability forecasting products besides traditional deterministic forecasting.

In summary, the operational forecasting agencies in the world have been researching and focusing on the 5 important problems mentioned above in numerical forecasting models. Therefore, in addition to improvements in model physics, increased resolution, etc., it is necessary to improve and update more accurately the initial conditions from data data by using data assimilation method.

1.1 Literature review in the world

a) Physical sensitivity test for the numerical prediction model

Numerical forecasting methods have received special attention in recent decades because of their ability to predict detailed tempo-spatial rainfall. Because the numerical model uses parameterization methods to solve planetary equations in general, equations cannot be solved exactly by analytical solutions. Therefore, parameterization schemes are developed to deal with physical processes with scales smaller than the grid resolution of the numerical model. One of the models developed by the scientific community in the direction of diversifying the above options is the WRF model. Weather simulation and forecasting models such as WRF have many different parameter schemes options, each scheme has different advantages and disadvantages, depending on the thermodynamic properties in the study area. Therefore, studies using the WRF model in very shortrainge quantitative rainfall forecasting for an area, research on physical sensitivity test needs to be carried out.

b) Data assimilation in rainfall forecasting

The history of data assimilation began in the 1950s and has a long history and has recently developed with the advancement of computer science and numerical modeling and the strong development of technical data assimilation. Assimilation methods and techniques are always improved and can be summarized as follows (Figure 1.1):

Figure 1. 1. General diagram of current data assimilation methods and techniques for numerical models (M. Asch, M. Bocquet, M. Nodet, 2017)

c) The radar assimilation studies for very short-range quantitative precipitation forecasting in the world.

Currently, radar observations have a lot of information and reflectivity and radial velocity of radar to assimilate to improve the rainfall forecasting ability. Nowadays, at operational forecasting agencies and research units, data assimilation, especially high-resolution radar data assimilation, updated hourly for numerical models is the main method and gives the best forecast results in rainfall forcasting. The application of artificial intelligence also keeps promise for improving forecast quality in general and improving rainfall forecasts from rapidly updated assimilation numerical model systems.

1.2 Literature review in Vietnam

Recently, in Vietnam, more applying numerical models in weather forecasts and research go into improving model parameters and model initial fields to achieve better forecast quality as Kieu Thi Xin ccs., (2005) Le Duc (2007) Huynh Thi Hong Ngu and La Thi Cang (2008) Tran Tan Tien and Nguyen Thi Thanh (2011) Tran Tan Tien ccs., (2013) . Du Duc Tien ccs., (2013, 2016), Ngo Duc Thanh (2014) . Tran Hong Thai ccs., (2016), Tran Duy Thuc ccs., (2018) Vu Van Thang (2020) Mai Van Khiem et al

CHAPTER 2: DATA AND METHODS FOR RADAR ASSIMILATION FOR MODEL IN THE VERY SHORT-RANGE QUANTITATIVE PRECIPITATION FORECASTING

2. 1 Regional model system applied in the thesis

a) Introduction to the WRF model

The Weather Research and Forecast (WRF) weather research and forecast model was developed by the United States' NCAR Atmospheric Collaboration Center. The WRF modeling system provides a variety of physics options that can be combined in many ways. The physical parameterization schemes in the WRF model are very rich, including Microphysical processes, parameterization of cumulus convection, planetary boundary layer, surface model and soil processes - surface, radiation and diffusion.

b) 3-DVAR assimilation in the WRF model

The 3D-Var three-dimensional variational assimilation method is researched and applied within the framework of the thesis. This is the solution to the 3-dimensional variational assimilation problem (3D-Var), but in reality, due to the very large amount of calculation, to minimize J(x) people use iterative methods such as such as conjugate gradient or *quasi-Newton* methods include four main steps as shown in Figure 2.2.

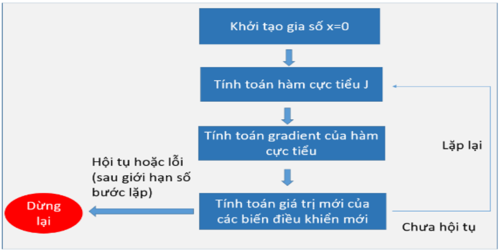


Figure 2.2. Iterative solution diagram of the three-dimensional variational method

c) Assimilate radar observation data for the WRF model

Although the response and radial wind are not input or fundamental variables in the model, through the assimilation method, specifically 3-Dvar in WRF, through observational and mathematical operators, the background field error match based on the physical transformation resulting from the above two factors will change the control variables and ultimately affect the model variables.

d) Rapidly updated radar data assimilation

Assimilation to update and improve the initial field is widely used in meteorological agencies around the world, such as the United States, Europe, Australia, Japan, Taiwan, Hong Kong (China), etc. in extremely short-term quantitative rain forecasting.

2.2. Data used in the thesis.

a) Hourly rainfall observation data

Observation data of 39 rain gauge stations in Ho Chi Minh City city area was collected and used to analyze and evaluate the forecasting ability of models with 15 heavy rainfall events in the period 2019-2021.

b) GFS data: GFS data with horizontal resolution of 0.5°x0.5° longitude and 0.25°x0.25° are exploited as input for the WRF model.

2.3. Evaluation Methods

The indicators to evaluate forecast results are as follows: FBI index; Probability of POD detection; FAR false prediction rate; CSI success score; Performance diagram, frequency chart.

CHAPTER 3. THE PHYSICAL SENSITIVITY TEST FOR HCM-RAP SYSTEM FOR VERY SHORT-RANGE QUANTITATIVE PRECIPITATION FORECASTING

3.1 Experiment Designs

With the goal of selecting and determining the optimal set of parameters to assimilate rapidly updated radar data for the HCM-RAP model to improve the accuracy of very short-range (1-6h) quantitative rainfall forecast for the HCM city area and improve accuracy as well as determine the specific contribution of reflectivity and radial velocity in forecasting of 1-6h leadtime with different rainfall thresholds. Research on and setting up the HCM-RAP system are as described above. In this system, the WRF model with the WRF-DA data assimilation module is used to assimilate radar data.

The assimilation system for rapidly updating radar data for extremely short-term quantitative rain forecasts (0-6 h) HCM-RAP is set up to run forecasts with hourly updates of radar data with 7 different physical combinations: ***Kain–Fritsch type 3 + Lin + Mellor–Yamada–Janjic; Grell–Devenyi + Lin + Mellor–Yamada–Janjic; Kain–Fritsch type 3 + WSM5 +Mellor–Yamada–Janjic; Grell–Devenyi + WSM5 + Mellor–Yamada–Janjic; Kain–Fritsch type 3 + New Thompson + Mellor–Yamada–Janjic; Betts–Miller–Janjic + New Thompson + Mellor–Yamada–Janjic***

3.2 Evaluate and propose the best physical diagrams to forecast very short-range quantitative precipitation for the HCM-RAP system

3.2.1 Spatial rainfall distribution of different physical parameterization combinations

The HCM-RAP system is set up to quickly update hourly reflectivity assimilation (ZH), radial velocity), reflectivity and radial velocity (ZHVR) and non-assimilation option (CTL) with a 6-hour forecast horizon with 7 different physical parameterization configurations, running simulations of 15 heavy rain events in 3 years 2019, 2020, 2021. To evaluate the ability to forecast rain spatially according to the Forecast term 1 - 6 hours for different hourly rainfall thresholds.

For 1-hour leadtime

Kain–Fritsch group type 3:

Figure 3.1 shows the spatial distribution of configurations combining different physical parameterizations ***Kain–Fritsch type 3 + New Thompson + Mellor–Yamada–Janjic*** with 4 options CTL, assimilation VR, ZH, ZHVR at forecast period 1 hour. The results show that the observed rain distribution of 15 experimental rains in 3 years 2019, 2020 and 2021 is mainly concentrated in the northwest and southeast areas of Ho Chi Minh city (circled with a red border). Comparing four different assimilation test plans, the results show that the non-assimilation plan tends to predict rainfall closer to observations than the other plans. However, in terms of forecasting heavy rain centers, the plan with the participation of ZH shows a tendency to forecast higher rainfall than in reality but forecasts heavy rainfall centers much better than the previous method. CTL non-assimilation plan and VR assimilation plan.

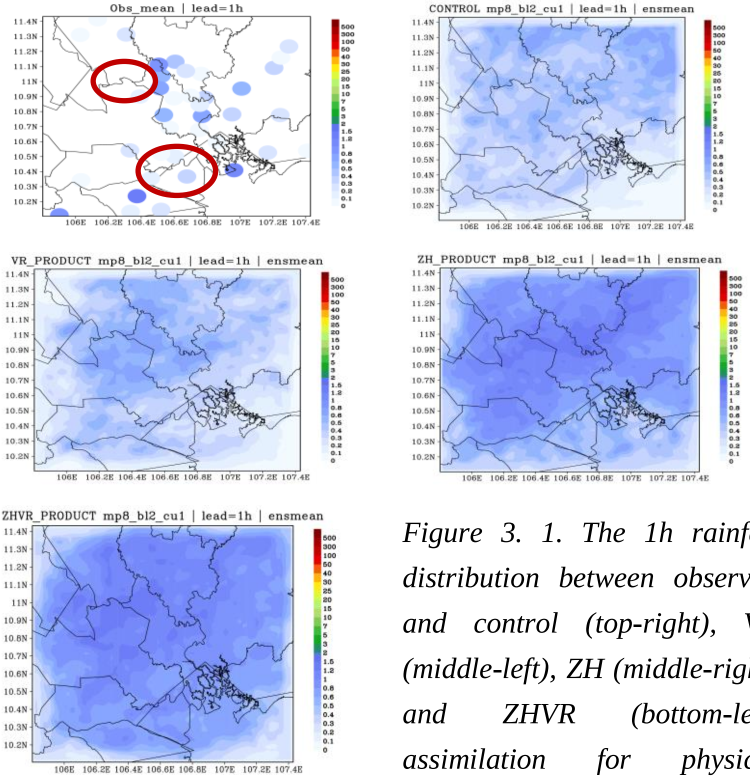


Figure 3. 1. The 1h rainfall distribution between observed and control (top-right), VR (middle-left), ZH (middle-right) and ZHVR (bottom-left) assimilation for physical combination KF3_THP_MYJ

Figure 3. 11 shows that with a forecast period of 1 hour, at the threshold of rain, the ZHVR combination assimilation plan gives the best forecast results with a POD score of about 0.7, 1-FAR ~0.3 and CSI ~0 ,25, then comes the ZH assimilation plan with insignificantly worse scores. The forecasting skill of moderate, heavy and very heavy rain thresholds of the two options ZH and ZHVR decreased but still had better skills than the other two options and was still predictable in practice. For the 1h limit, two configurations combine different physical parameterizations Kain–Fritsch type 3 + New Thompson + Mellor–Yamada–Janjic; Betts–Miller–Janjic + New Thompson + Mellor–Yamada–Janjic (KF3_THP_MYJ-mp8_bl2_cu1;BMJ_THP_MYJ-mp8_bl2_cu2) showed better prediction skills than the remaining different physical parameterization combinations.

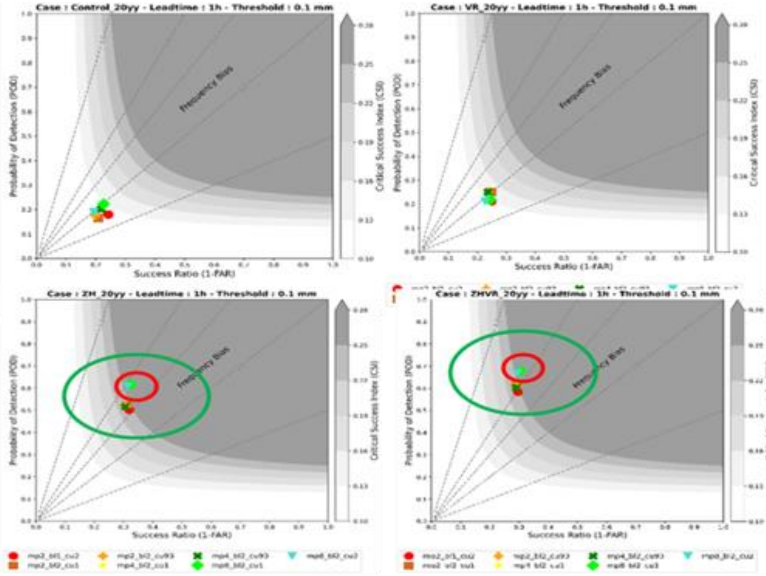


Figure 3.11. Performance diagram for the case of no assimilation (upper left), VR assimilation (upper right), ZH (lower left) and

combined assimilation ZHVR (lower right) 1 h cumulative rain forecast of 7 configurations combines different physical parameterization with 1h forecast ahead and 0.1mm/h rain threshold (~precipitation)

Figure 3.3 is similar to figure 3.1 but for the spatial distribution of configurations combining different physical parameterizations ***Kain–Fritsch type 3 + WSM5 + Mellor–Yamada–Janjic*** with 4 CTL options, concurrent VR, ZH, ZHVR at 1h forecast horizon. The results show similarities with Figure 3.2, however, there is a notable point related to the participation of WSM5 microphysics.

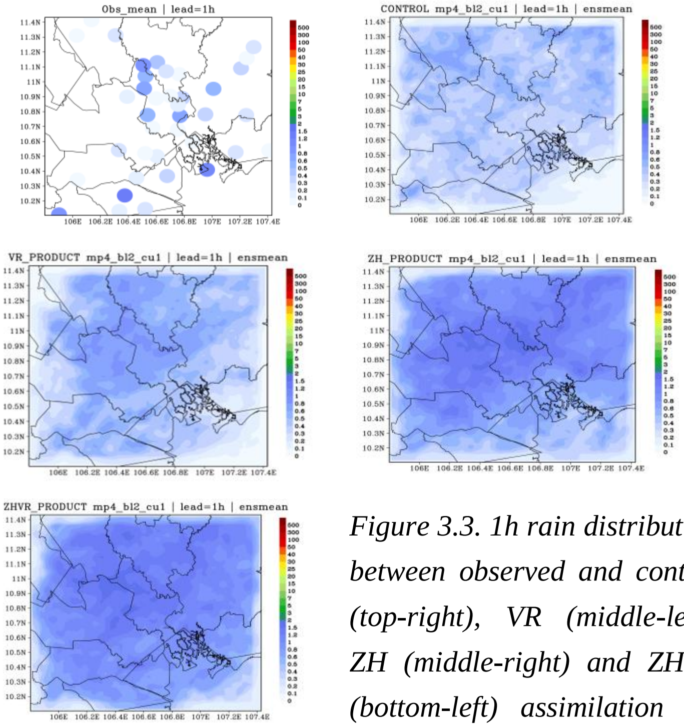


Figure 3.3. 1h rain distribution between observed and control (top-right), VR (middle-left), ZH (middle-right) and ZHVR (bottom-left) assimilation for physical combination KF3_WSM5_MYJ

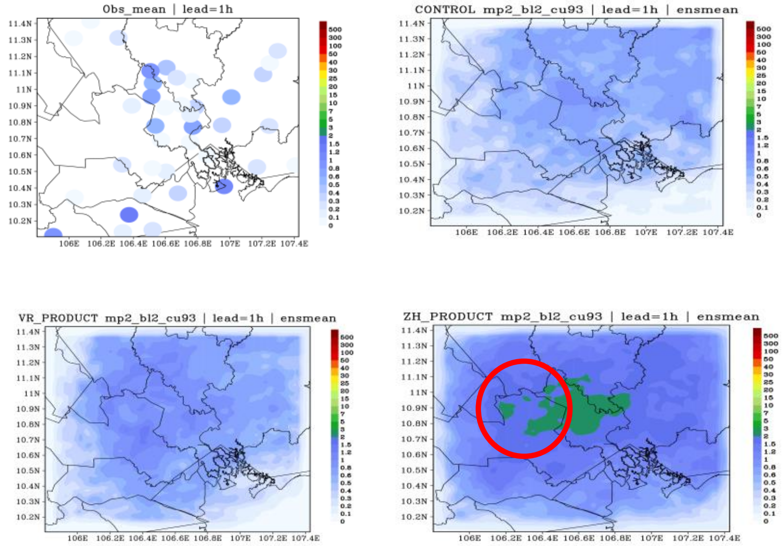
Overall, WSM5 microphysics predicts significantly lower precipitation than the two alternatives using the same Kain–Fritsch type 3 configuration.

As stated above the KF convection scheme is based on an outflow and inflow model that can simulate the ups and downs of the mass fluxes and incorporates an additional turbulence process depending on the relative humidity. Especially in the current WRF model, the KF scheme has up to 3 different variations such as the scheme using Fritsch–Chappell convection activation (KF1), activation based on vertical transport of moisture (KF2) and an additional relative humidity-dependent turbulence process related to the first triggering mechanism (KF3). KF3's activation mechanism is based on the vertical transport of moisture and additional turbulence depends on relative humidity, so it is quite sensitive and suitable for the above situation and mechanism of heavy rain in the city. Ho Chi Minh City is mainly economic area due to the influence of the southwest monsoon along with turbulence of the trough.

Grell group

Figure 3. 4 is similar to figure 3.1 but for the spatial distribution of configurations combining different physical parameterizations ***Grell + Lin + Mellor–Yamada–Janjic*** with 4 options CTL, assimilation VR, ZH, ZHVR at 1h forecast horizon. Comparing 4 different assimilation tests, it is found that the non-assimilation and VR assimilation plans give lower rainfall and do not predict heavy rain centers close to observations. In the presence of ZH, the rainfall is higher than the actual amount, but the prediction of heavy rain centers is better than without VR assimilation and assimilation, especially the ZHVR combination assimilation plan predicts a very extreme rainfall, being more presentable than reality

(circled in red).



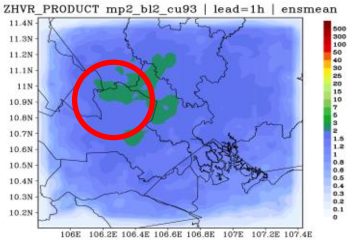


Figure 3. 2. 1h rain distribution between observed and control (top-right), VR (middle-left), ZH (middle-right) and ZHVR (bottom-left) assimilation for physical combination GD_LIN_MYJ

In general, the group of configurations combining different physical parameters of the Grell family predicts a 1-hour drought that is much higher and more extreme than in reality. This may be because the Grell-Devenji scheme reference is a synthetic convection scheme and has recently been used in high-resolution modeling. This diagram uses reference equations to calculate meteorological parameters such as wind speed, humidity, and temperature in the atmosphere, making it possible for the model to simulate various weather phenomena and a diagram improved as well as often triggering heavier than normal rain and used for the purpose of forecasting rainfall extremes.

Betts–Miller–Janjic group

For the 1h term, **the Betts–Miller–Janjic + New Thompson + Mellor–Yamada–Janjic combination** in Figure 3.6 shows a similar trend to the Kain-Frisch 3 group.

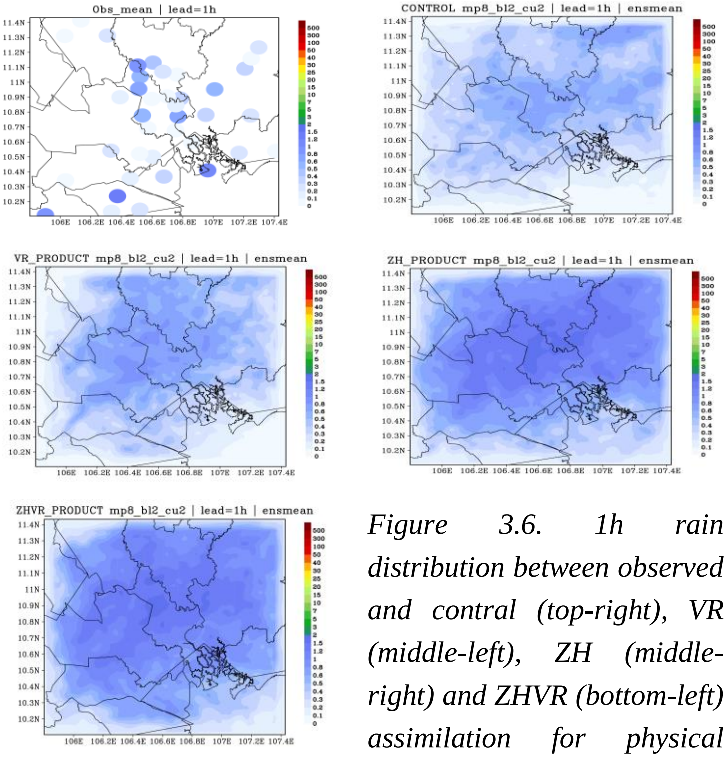


Figure 3.6. 1h rain distribution between observed and contral (top-right), VR (middle-left), ZH (middle-right) and ZHVR (bottom-left) assimilation for physical combination BMJ_THP_MYJ

The 3h and 6h term also gives a similar picture to the 1h term.

When considering seven different physical parameterization combinations for three groups of convective schemes, including Kain–Fritsch type 3, Grell–Devenyi, and Betts–Miller–Janjic, the results show that the convective scheme group The Grell–Devenyi model predicted rainfall over 1-hour, 3-hour, and 6-hour periods at higher biases than the other two groups and generally predicted rainfall at higher levels than actuals.

3.2.2 Rainfall frequency distributions

For 1-hour leadtime

To evaluate the role and distribution of observed and forecasted rainfall frequency of different physical combinations at forecast horizons, the researcher used frequency-histogram and KDE-histogram observed and forecast at 39 monitoring stations as mentioned in Chapter 2.

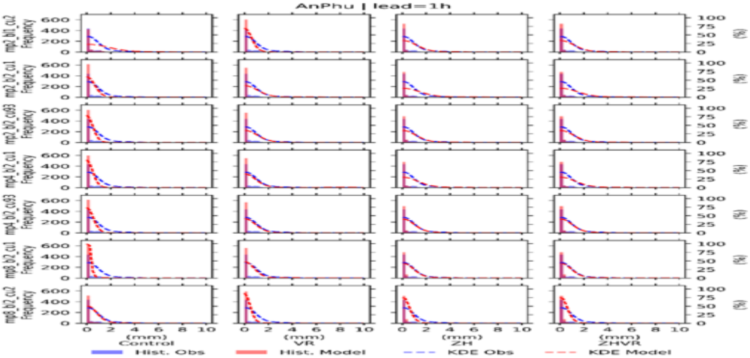


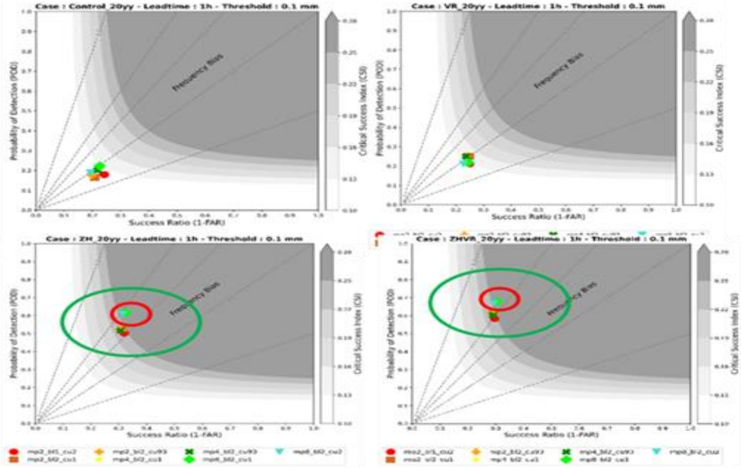
Figure 3.8. Frequency-histogram chart at An Phu station for 1-hour drought between observed rain (blue column) forecast rain (red column) and observed KDE-histogram (blue dashed line) and observed KDE-histogram blue dashed) with unassimilated (left), VR (left-middle), ZH (right-middle) and ZHVR (right) assimilation experiments for different physical parameterization combinations

Figure 3.23 with the horizontal axis is the hourly rain thresholds (mm/h) from 0-25mm with each bin being 0.2 (jump), the vertical axis on the left shows the frequency of occurrence of rain distributions for the combinations. The physical and pineal axis must reflect the corresponding percentage. The combined group of KF3, BMJ and New Thompson physical diagrams and MYJ boundary layer diagrams shows that the frequency distribution according to the forecast rain thresholds is closest to the observations and also shows more skill with the forecasted rainfall thresholds. Meanwhile, the group with Grell's presence predicted a much higher bias than observations at the limits and stations through the KDE-histogram forecast spreading to the thresholds of 4-5mm/h and quite far compared to the forecast. with KDE monitoring.

3.2.3 Evaluate the forecasting skills

For 1-hour leadtime

For the 1-hour forecast leadtime, the HCM-RAP system gives very good forecasting skills compared to forecasting the threshold of rain, which is quite good for the threshold of moderate rain and not so good for heavy and very heavy rain. Although the forecasting skills of the two options ZH and combination decrease rapidly, they still have certain skills and are slightly better than the two options without assimilation and VR assimilation. Specifically, at this 1h limit, it is seen that the two configurations combine different physical parameterizations **Kain–Fritsch type 3 + New Thompson + Mellor–Yamada–Janjic; Betts–Miller–Janjic + New Thompson + Mellor–Yamada–Janjic** shows more skill than the remaining configurations



combining different physical parameterizations (Figure 3.11).*Figure 3.11. Performance diagram for control (upper left), VR assimilation (upper right), ZH (lower left) and combined assimilation ZHVR (lower right) for 1 h cumulative rain forecast of 7 different physical parameterization combinations with 1 h forecast leadtime and 0.1mm/h rain threshold (2.4mm/day)*

These combinations are also very suitable for comparative studies evaluating the effectiveness of 1-hour data updates compared to 3-hour and 6-hour data updates for the WRF weather forecast model for forecasting extreme rainfall, especially in the assimilation involving radar return and radial wind data.

3.2.4 Propose the best physical parameters for HCM-RAP system

Test results of 7 different multiphysics combination configurations in HCM-RAP, 2 configurations combine different physics parameterizations **Kain–Fritsch type 3 + New Thompson + Mellor–Yamada–Janjic; Betts–Miller–Janjic + New Thompson + Mellor–Yamada** with ZHVR and ZH ensemble assimilation shows more skills than the remaining configurations combining various physical parameterizations.

CHAPTER 4. THE CONTRIBUTION OF RADAR DATA IN HCM-RAP SYSTEM IN VERY SHORT-RANGE QUANTITATIVE PRECIPITATION FORECASTING

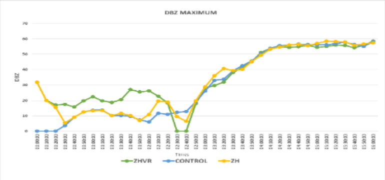
The two best physical combinations are selected in section 3. 2. 4 **Kain–Fritsch type 3 + New Thompson + Mellor–Yamada–Janjic and Betts–Miller–Janjic + New Thompson + Mellor–Yamada** are used for the Analyze, evaluate and comment on specific details compared to station and radar observations.

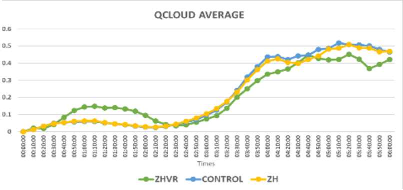
4.1 The role and influence of radar data in assimilating rapid updates for the WRF model predicting extremely short-term rain in the city area. Ho Chi Minh

4.1.1 Initial field comparison between assimilated and non-assimilated fast updates

Figure 4.7-8-9-10 (combined) shows that at the initial time, the reflectivity and radial velocity have a clear influence, not only changing the response field and wind field but also changing other meteorological fields such as temperature.

From the above results, it can be seen that ZHVR and ZH radar data assimilation have a strong impact mainly in the first 2 hours of the model. In other words, the role of putting radar data into the HCM-RAP model system is effective in the first 2 hours. Therefore, the assimilation and updating of radar data for HCM-RAP is best done with an input frequency of at least 2 hours apart and 1 hour is the most optimal.





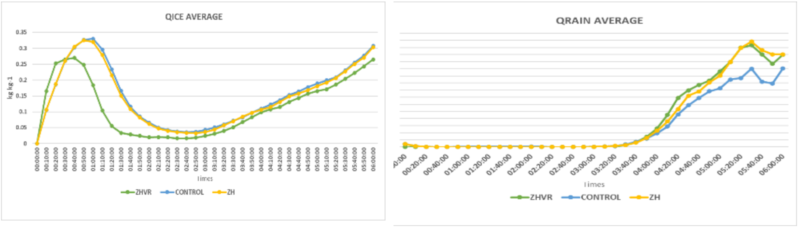


Figure 4.7-8-9-10 (combined) MDBZ, QRAIN, QICE, QCLOUD over time from 00:00 to 06:00 with a 10-minute time step

4.1.2 Role and influence of radar data in rapid update assimilation

Figure 4.18 shows that HCM-RAP predicts the CSI success index of these two options is also very low, less than 0.15 (15%) for droughts at the rain threshold and without skill at the remaining rain thresholds. Meanwhile, the CSI success index of ZH and ZHVR is much higher than the previous two options and reaches nearly 0.3 in the 1-hour rain drought and ~0.17 in the 3- and 6-hour drought. The remaining rain thresholds also show much greater skill than the previous two options and are on average **1.5 to 2 times higher** than the previous two options. The CSI index also shows that the ZHVR option is the option with the highest rain storm prediction skill, which can reach nearly 30%, **about 2 times higher** than the CTL option.

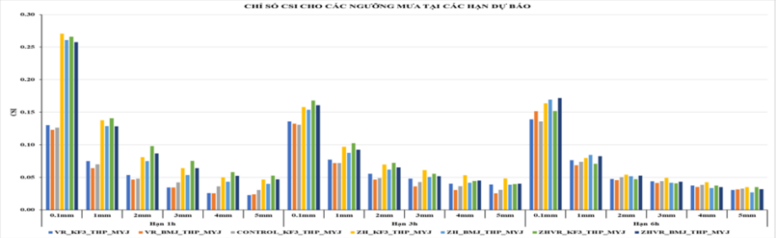


Figure 4.18 CSI evaluation index of the 2 best physical options with VR assimilation (columns 1 and 2 from left), 1 best physical option CTL (yellow column) and 2 ZH options (column 4 , 5 from left), 2 ZHVR options (columns 6, 7 from left) rain forecast

4.2 Comparison of radar extrapolation and HCM-RAP forecast

Figures 4.23 show that in the first 4 h of extrapolation the radar is more skilled for all rainfall thresholds. However, from 4 to 6 o'clock, HCM-RAP shows superior skills compared to radar extrapolation. Especially the heavy and very heavy rain threshold (2mm/h and 5mm/h). This shows that in practice it is necessary to build a blending technique to extrapolate radar and assimilate quick hourly updates for each specific area according to each season and each situation that causes the risk of steady rain in extremely short duration.

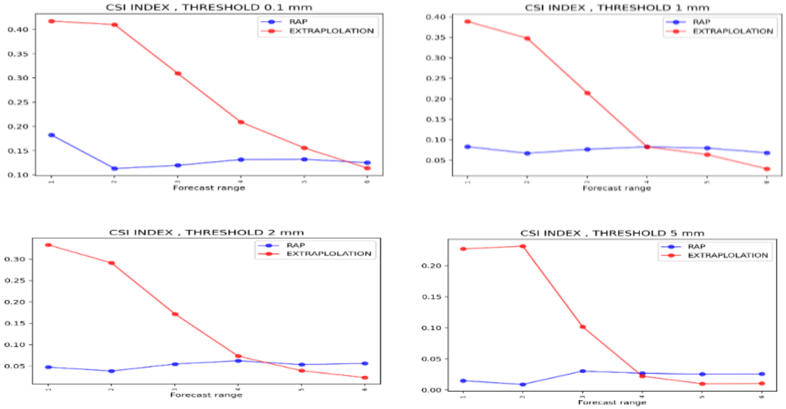


Figure 4.23. CSI evaluation index of the HCM-RAP system and extrapolation of Nha Nha Be radar with thresholds of 0.1, 1.2 and 5mm/h from 1 to 6 hours

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

(1) Building and testing the HCM-RAP rapid update assimilation system very short-range quantitative precipitation (1-6 hours) for the Ho Chi Minh City area. Radar data are processed and digitally assimilated (reflectivity and radial velocity) hourly with radar observation frequency of 15 minutes for 7 different physical combinations with 4 modes running (CTL, VR, ZH, ZHVR assimilation methods) for 15 rainfall events in the 3 years 2019-2021.

(2) Analyzing and evaluating the forecasting skills of different physical parameterization configurations for the HCM-RAP system according to spatial distribution and frequency according to rainfall thresholds for forecast and forecast-ranges. The suitable physical parameterizations for the HCM-RAP system are: Kain–Fritsch type 3 + New Thompson + Mellor–Yamada–Janjic and Betts–Miller–Janjic + New Thompson + Mellor–Yamada.

(3) The thesis has analyzed and evaluated the effectiveness of reflectivity and radial velocity in rapid update assimilation. It shows that reflectivity has the biggest influence in improving the skill of very short-range quantitative precipitation forecasting in compared to non-assimilating.

(4) Assimilation of radar data updates for HCM-RAP is best performed with an update frequency of at least 2 hours apart, and 1 hour is the most optimal.

(5) The quantitative forecast of 4-6 hours leadtime indicated that it is better than in comparison to radar extrapolation, it will be solving the aboved gaps and in association with radar

extrapolation of 1-3 hours ahead to improve the quality of very short-range quantitative precipitation forecasting for the Ho Chi Minh City area.

Recommendations

(1) Quantitative rainfall forecasting very short-range quantitative precipitation is a difficult problem and is currently a challenge for the world and our country. To apply the HCM-RAP system into operational forecasting, more experiments are needed in updating other monitoring data besides radar such as satellite, surface and combined.

(2) The HCM-RAP system needs to apply digital filter initial.

(3) The HCM-RAP system is built based on 3DVAR assimilation, so there are still internal limitations of 3DVAR, so it requires conversion/additional tests to test other methods such as GSI, Kalman filter combination, 4DVAR...to improve the ability to forecast.

(4) Application in operational forecasting of extremely short-term rain requires research and development of a blending technique to extrapolate radar and assimilate quick hourly updates for each specific area according to each season and each causing situation.