MINISTRY OF RESOURCES AND ENVIRONMENT
INSTITUTE OF METEOROLOGY, HYDROLOGY AND CLIMATE CHANGE

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THE EFFECTS OF TOPOGRAPHY AND COLD SURGES ON STRUCTURE OF TROPICAL CYCLONES OVER VIETNAM COASTAL REGIONS

Meteorology and Climatology Major
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SUMMARY OF DOCTORAL THESIS ON METEOROLOGY AND CLIMATOLOGY

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INTRODUCTION

1. Reason for choosing the topic

Typhoons and tropical depressions (known as as tropical cyclones, TCs) are weather extreme phenomena, TCs usually accompany with heavy rains and strong winds, often cause natural disasters such as severe floods or storm surges where the tropical cyclone passes. According to the World Meteorological Organization, over the past 50 years, there have been 1,942 natural disasters caused by tropical cyclones, killing 779,324 people and causing economic losses of 407.6 billion USD, on average 43 deaths and $78 million damage every day. Vietnam locates in the region of the Pacific Northwest hurricane with about 30 tropical cyclones per year, accounting for 38% of the global tropical cyclones. One of the efforts to reduce the damages of property and people due to tropical cyclones is to predict the typhoon track with relative accuracy. Currently, the numerical models for weather and typhoon forecasting purposes have been applied in operation and research in Vietnam. In addition, Vietnam also consulted the operational products of major centers in the world. However, the typhoon forecast quality of the models sometimes does not meet the actual requirements due to the large error in track prediction.

As the typhoon approaches the shore, forecasting the typhoon track is more complicated due to the interaction between the typhoon and the topography as well as the weather patterns. Depending on the speed of movement, intensity and topography’s type that the typhoon passes through, the area affected by the typhoon will have different structure of meteorological fields, especially precipitation and wind. Beside the topography, cold surge (KKL) also has significant effects on typhoon’s structure and intensity, especially in strong or intensification events.

2. Research question

How will the typhoon be affected by Vietnam's topography? What will the structure of the meteorological fields be when the typhoon approaches the coast of Vietnam with cold surge penetration? What mechanism controls these effects? Those questions have not been satisfactorily answered. Because of the above reasons, the topic "The effects of topography and cold surges on structure of tropical cyclones over vietnam coastal regions " was chosen to study the typhoon's track, structure, especially, the structure of precipitation and winds when tropical cyclones are affected by cold surge and Vietnam's topography.

3. Objectives of thesis

- To simulate the influence of Vietnam's topography on the symmetrical structure of the typhoon before and after the typhoon hits the coast of Vietnam.

- To assess the influence of cold surge on structure of typhoon’s fields in the East Sea;

4. Object and scope of research

- ***Research objects***

+ Tropical cyclones in the East Sea, especially those affected by cold surge and make a landfall in the coastal area of Vietnam;

+ The impact of Vietnam topography on the typhoon structure.

- ***Research scope***

+ Spatial scope: the East Sea and coastal areas of Vietnam

+ Period: 2014-2018

5. Research Methods

- Numerical method: simulating the structure of meteorological fields and forecasting selected tropical cyclones in the thesis.

- Synoptic method: analyzing medium and large-scale patterns during the formation, development and landfall of tropical cyclones in the coastal areas of Vietnam.

- Statistical method: used to make statistics of tropical cyclones; calculate, compare, evaluate error of intensity, track and meteorological fields in tropical cyclones.

6. New contributions of the thesis

- Clarifying the mechanism and influence of Vietnam's topography on the structure of the cloud fields, the wind, the distribution of rainfall and the deviation of the track when the TC nears the shore and landfalls;

- Clarifying the mechanism and influence of cold surge on the structure of the cloud field, the distribution of rainfall and strong winds in tropical cyclones on the East Sea of Vietnam.

7. Theoritical argument

- Vietnam's topography affects the structure of meteorological fields of tropical cyclones before and after landfalling.

- When there is the impact of cold surge, the vortex structure of tropical cyclones in the East Sea will be changed.

8. Scientific and practical significance

- The research results on the role of topography altitude and cold surge to the structure of meteorological fields in tropical cyclones can serve as a scientific basis for determining the landfall area of TC and the area that has heavy rain and strong wind due to the impact of topography and cold surge;

- Research results contribute to improving the understanding of the influence of topography altitude and cold surge on TC structure, thereby contributing to improving the quality of TC forecasting in Vietnam, especially in areas affected by heavy rain and strong winds, to help prevent and minimize the damage caused by tropical cyclones.

CHAPTER 1: OVERVIEW OF RESEARCH WORKS ON THE EFFECT OF TOPOGRAPHY, COLD SURGE ON TROPICAL CYCLONE STRUCTURE

1.1 THEORETICAL BASIS OF TROPICAL CYCLONE

Tropical cyclone is a common name of typhoon and tropical depressions. Tropical cyclone is an area of vortex winds with a diameter of hundreds of kilometers, forming over tropical seas. In the Northern Hemisphere, the wind blows towards the center in a counter-clockwise direction, whereas in the Southern Hemisphere the wind blows towards the center in a clockwise direction, the atmospheric pressure in the tropical cyclone is lower than that in the surrounding area, there is rain, sometimes accompanied by thunderstorms, storms, whirlwinds. Depending on the strongest wind speed in the area near the center, tropical cyclones are divided into tropical depression or hurricanes. Atmospheric pressure in typhoon is lower than in tropical depression and is usually less than 1000mb (Gray, 1967).

Tropical cyclone is a tropical depression with strongest winds from level 8 and possible gusts. The typhoon with the strongest wind from level 10 to level 11 is called strong typhoon, from level 12 to level 15 is called a very strong typhoon, from level 16 and above it is called a super typhoon.

1.2 OVERVIEW OF RESEARCH WORKS IN THE WORLD

In the period before 1970, rapid development of reconnaissance aircraft, radar, satellite and computer technology in the post-World War II period and advances in research by scientists are important prerequisites in the development of typhoon structure research and forecast later.

From the 1970s to the present, surveillance technology has improved alot. Since 1987, hazardous weather events including typhoon have been observed by Doppler radar to provide more valuable information about the typhoon's thermodynamic structure. Perhaps the most notable advancement is satellite remote sensing technology (Ackerman et al., 2019; Fu et al., 2019). Over the decades, satellites have continuously improved image resolution quality over both space and time. From the large data sets collected from modern equipment, during this period, scientists have made great strides in studying typhoon structure. There have been a large number of published studies on the symmetrical structure of tropical cyclones, especially the concentric eyewall structure, but the published theories have not yet reached a high consensus. An important unresolved question is whether the typhoon's structure is affected by external atmospheric conditions (e.g. interactions with surface elements or nearby weather systems) or by the internal instability of the typhoon, or possibly both.

From 2000 to 2015, many scientists used numerical models to simulate the effects of topography on typhoon track, including studies using real topography (Wu 2001; Jian and Wu 2008; Huang et al. et al 2011) and idealized empirical studies (Chang 1982; Bender 1987; Yeh and Elsberry 1993; Lin et al 1999; Wu and Kuo 1999; Lin and Savage 2011; Hsu et al 2013; Tang and Chan 2013; Wu et al. 2015, Hiep NV and Yi-Leng Chen 2011). Numerical simulations with various idealized designs used in these studies have provided additional insights into topographical changes to typhoon movement.

1.3 OVERVIEW OF RESEARCHES IN VIETNAM

Since the 1960s, Vietnamese meteorologists have had a number of research works on the cold surge, tropical cyclone, frequency of the tropical cyclone, the season of the tropical cyclone, the intensity of the tropical cyclone, movement direction of the tropical cyclone and the impacts of the cold surge on the tropical cyclone.

In Vietnam, a number of studies on vortex initialization have been carried out to improve the predictive quality of the model. Bui Hoang Hai and Phan Van Tan (2002) investigated the effect of initialization on the forecast track by running WBAR models for 3 tropical cyclones Durian (2001), Kajiki (2001), Wukong (2000). The results show that vortex initialization has contributed to reducing the position error of the forecast track. Phan Van Tan and Nguyen Le Dung (2008) built an artificial vortex by assimilating the bogus observation data from the three-dimensional variable data assimilation (3D-VAR) module in WRF model to forecast experimentally 10 tropical cyclones in the East Sea during the period from 2006 to 2008. Research results showed that the use of "bogus" datasets has significantly improved the quality of typhoon track forecasts, especially for strong tropical cyclones. Tran Tan Tien and Le Thi Hong Van (2009) studied the influence of artificial vortex constituents in the assimilation of bougs vortex data by using the WRF model for Lekima typhoon, determined that the vortex initialization plays an important role on improving the quality of typhoon forecasts, especially in terms of intensity. Du Duc Tien et al (2016) used simultaneously wind monitoring information at high altitudes from calculating the cloud displacement data provided by the University of Wisconsin, USA to build a full three-dimensional vortex model by using the Kalman filter assimilation method (LetKF) for the WRF-ARW model. The study was conducted experimentally on Typhoon Usagi (2013) on the Pacific Northwest region. The results show that the inclusion of observational information contributes to improve the quality of track forecaste at almost forecast time.

From the works related to cold surge affecting tropical cyclone, some comments can be drawn as follows:

- Most of the authors mentioned the appearance of cold surge at low latitudes in winter and summer, which affects the formation, development, and direction of tropical cyclones, as well as the variability of extratropical cyclones;
- The main research methods are synoptic statistical analysis, and satellite cloud image analysis with thermal and humid factors. In recent years, by using numerical models, the authors have studied the process of the influence of extratropical cyclones, mainly the transformation into extratropical cyclones in the mid-latitudes.
- Domestic studies mainly focused on statistical methods, vortex installation, noise farming, data assimilation, development of an ensemble forecasting system to forecast typhoon track. Although there have been some previous studies on topographic and monsoon influences on tropical cyclones, there has not been a complete and in-depth study on the mechanism of these effects. Therefore, this study uses observational data

sources combined with numerical modeling to further study and explain: (1) the influence of topographical and cold surge on typhoon structure in cold surge and (2) on the basis of simulation product of typhoon structure by the numerical model, explain which mechanism affects the topography, cold surge on typhoon structure in the East Sea.

CHAPTER 2: DATA AND METHODS

2.1 DATA

In this study, the best track dataset of 18 typhoons in the period 2014-2018 was exploited at the website of the Japan Meteorological Agency (JMA) and of the US Joint Typhoon Warning Center (JTWC) and is used as an input to the vortex initialization program. Initial field data and time-dependent boundary conditions were obtained from the US National Center for Environmental Prediction's (NCEP) FNL analysis product.

Convection activity was tested using data from the atmospheric infrared sounder (AIRS) sensor located on the National Aeronautics and Space Administration (NASA) Aqua satellite.

2.2 METHODS

2.2.1 Numerical modeling method

The thesis uses model ARW-WRF version 3.8 to simulate typhoon structure. The model has a pressure coordinate system with pressure values at the surface and top of the atmosphere being constant. The basic physical process options of the model include: WSM6 cloud microphysics (MP) scheme, Goddard (Tao, 2003); Betts – Miller - Janjic (BMJ), Grell-Devenyi (Grell and Devenyi, 2002) convective parameterization scheme; Monin-Obukhov surface layer scheme; Noah LSM topsoil scheme ; Rapid Radiative Transfer Model (RRTM) longwave radiation scheme; Duhia shortwave radiation scheme and Yonsei scheme for planet boundary layer; YSU planet boundary layer scheme (Hong, 2006). More details on the WRF model can be found in Skamarock (2008).

2.2.2 Vortex initialization method

2.2.2.1 Dynamical Vortex Initialization

Vortex initialization is a technique to construct a bogus vortex with structure and intensity close to the real cyclone, coincident with the observed cyclone location to replace the low-resolution vortex from global analysis (Mathur 1991, Kurihara et al. 1993) to improve the initial conditions for numerical models. This thesis applied the NC2011 dynamic vortex initialization method developed by Nguyen Van Hiep and Yi-Leng Chen (2011) to create an initial field for the WRF model to predict the intensity and track of tropical cyclones, especially tropical cyclones affected by cold surge over the East Sea. This is a method of initialization through the cycle technique to create high-resolution initial conditions for numerical models.

To obtain a bogus vortex, the following processes are applied to each variable F at the beginning of each cycle run:

$$F^{V}_{c+1,t0,x,y,z}=F^{V}_{c,t0,x,y,z} + f^{V}_{c,t0,x,y,z} \text{ với } c=1,...,N$$

Where x, y, z are spatial coordinates, F^{V}_{c} and F^{V}_{c+1} are vortex parts of variable F in c loop and in c+1 loop at the initial time t0 of model; f^{V}_{c} is the difference in the vortex component of the variable F at period c between the initial time and the initial time plus dt. In this case dt is 60 minutes. N is the number of iterations.

2.2.2.2 Votex Relocation

The vortex relocation method used in the thesis is to reduce the error of the tropical cyclone position in the initial field compared with the observed position and is performed after the WPS pre-processing step. The initial field and observed value were then assimilated by WRFDA to generate the model's initial condition. The first step of the vortex relocation method is to separate the vortex from the environment in the initial diagnose field, this step used the vortex separation technique of Kurihara (1995) and additionally used the maximum vortex value at 850 hPa to locate the center of tropical cyclone to remove near-surface disturbances (Hsiao, 2010).

2.2.3 Methods to determine the influence of cold surge on tropical cyclones in the East Sea

In order to study the influence of cold surge on tropical cyclones, the thesis has chosen to build indicators by using synoptic statistical methods, analyzing pressure and streamline fields. Based on the dataset of the typhoon activity schedule in the East Sea and the cold surge activity from September to December in the study period, combined with the analysis of the pressure field and the streamline field to select the tropical cyclones above on the East Sea that coincided with or nearly coincided with that of cold surge, then checked it by analyzing the pressure field and streamline field at surface levels and 925mb, then identify tropical cyclones affected by cold surge.

A typhoon interacting with cold surge used in this thesis satisfies two criteria: (1) the typhoon must be active during the period of strong cold surge (September to December); (2) during the active typhoon period, there exists at least one time when the typhoon center is less than 300 km from the 1020 hPa isobar.

2.3 EXPERIMENT DESIGN

The physical choices of the model are similar to those of Nguyen and Chen (2011).

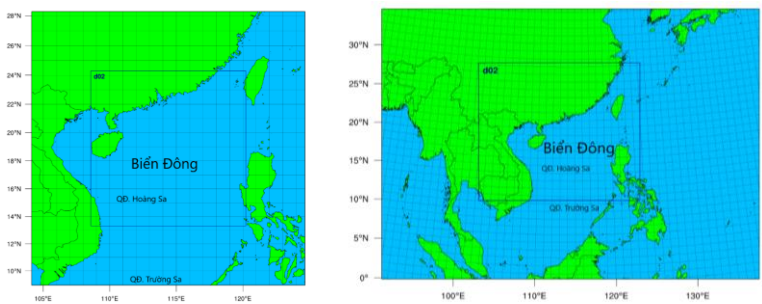


Figure 2.2: domain used in vortex initialization (left) and simulation (right).

To evaluate the impact of vortex initialization, the thesis chooses simulations for tropical cyclones passing through the 120°E of 5 typhoon seasons from 2014 to 2018. The physical options and vortex initialization include: Default (CTL), False Vortex (BG), Vortex Relocation (RL), Dynamic Initialization (NC).

To evaluate the impact of topography on the structure of 5 tropical cyclones under the impact of cold surge, the thesis changed the topography altitude with the experiments designed as follows: Reduce the topography elevation for the whole region to 2m (TER2m), reduce topography height by 50% (TER50), reduce topography height by 75% (TER75) and increase topography height by 150% (TER150).

CHAPTER 3: RESEARCH RESULTS ON THE EFFECT OF TOPOGRAPHY, COLD SURGE ON TYPHOON STRUCTURE

3.1 INCREASE THE QUALITY OF INITIAL FIELD BY VORTEX INITIALIZATION METHOD

In order to select the most suitable vortex initialization to predict the typhoon track as well as intensity and assess the influence of cold surge and topography on the structure of tropical cyclones, the thesis carried out 228 experiments on the structure of 18 tropical cyclones, including 05 tropical cyclones with cold surge influence and 13 unaffected tropical cyclones.

Table 3.2: Intensity error and mean distance of 228 experiments

Experiment type	Error Pmin (mb)	Error Vmax (m/s)	Average distance error
CTL	9.5	6.6	137.7
BG	10.6	7.7	129.6
RL	8.8	6.8	127.1
NC	8.3	6.4	112.5

Comparison of intensity error and mean distance between experiments showed that for most tropical cyclones, the NC dynamic vortex initialization scheme gave the smallest prediction error in both intensity and distance. The mean distance and magnitude error of the NC program are reduced by about 18.3%, 3% (Vmax) and 12.6% (Pmin), respectively, compared with the default case (CTL) whereas the RL vortex shiftting and bogus vortex (BG) scheme have larger error results. That means that the NC dynamic vortex initialization scheme helps to increase the accuracy of typhoon track and intensity prediction on WRF model.

3.2 THE ROLE OF TOPOGRAPHY IN TYPHOON STRUCTURE, TRACK, AND INTENSITY

3.2.1 The role of topography on the structure of the meteorological field in tropical cyclones

Research results show that due to the impact of surface friction caused by topographic elevation, the structure of the cloud field and the eye of the typhoon is broken and the higher the topography, the greater the asymmetry of the cloud field; the time that Damrey makes a landfall time of Damrey in the case of topography decrease occurs 1 to 2 hours earlier than the default case, while in the case of topography elevation, the typhoon makes a landfall about 4 hours later.

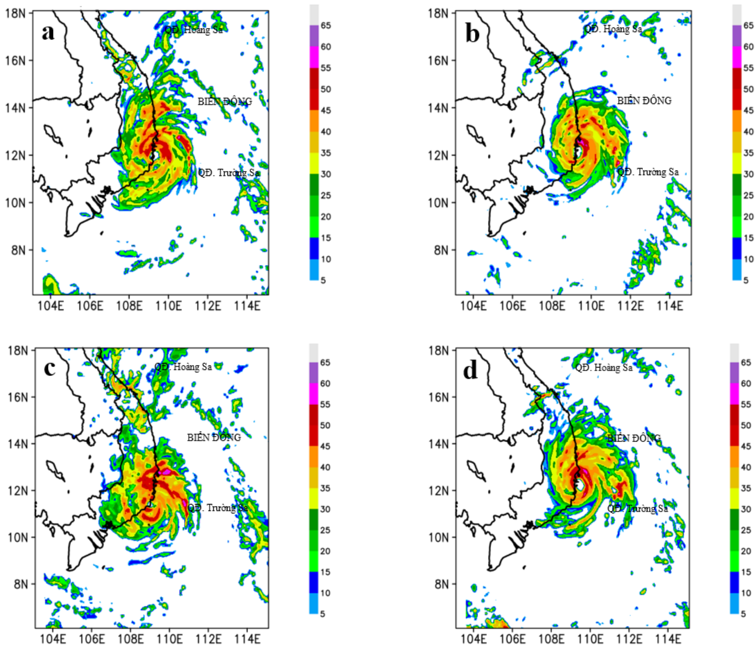


Figure 3.12: Damrey typhoon cloud field structure (2017) through radar reflextivity (measurement unit: dbz) at the time of typhoon landfall in the cases of (a) CTL, (b) TER2m, (c) TER150 and (d) TER50

Regarding the minimum pressure (Pmin) at the typhoon center, in all cases, these values were largest in the highest altitude experiment, while the minimum values were seen in the experiment reduced the altitude to 2m. According to the simulation results, the minimum pressure in the topography altitude reduction experiments is larger than the default case and vice versa. Specifically, 3 hours before the typhoon makes a landfall, Pmin in the TER150 experiment reached the highest value of 987 mb, while this data for the other cases are 973mb, 976mb, 978mb in the TER2m, TER50 and defalt experiment respectively. Thus, typhoon Pmin will decrease with increasing topography altitude and increase with decreasing topography altitude.

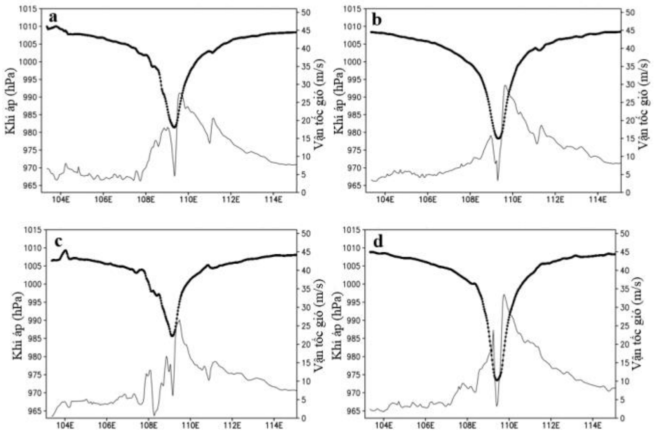
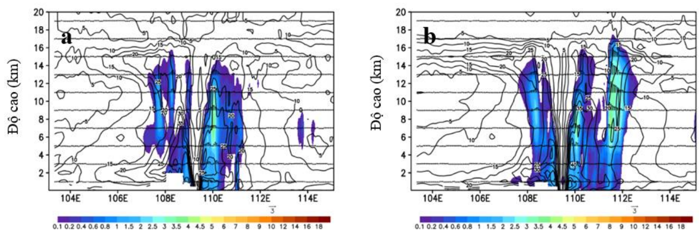


Figure 3.16: Vertical cross-section of sea level pressure (dark black line) and 10 meters level wind (thin black line) through the typhoon center at typhoon Damrey (2017) landfall in cases (a) CTL, (b) TER50, (c) TER150 and (d) TER2m



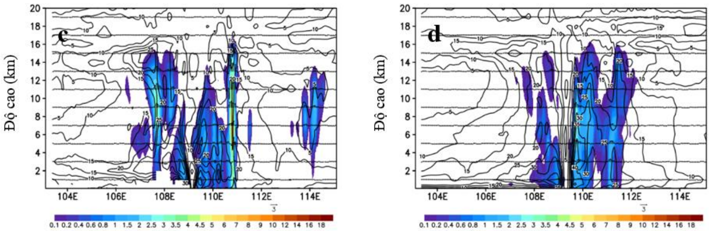
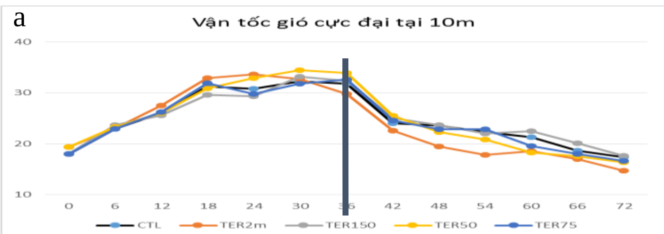


Figure 3.19: East-west cross-section through the center of Typhoon Damrey (2017) of wind speed (solid line), mixing ratio (color) and vertical speed (vector) of landfall in cases (a) CTL, (b) TER50, (c) TER150 and (d) TER2m

The study results also showed that the distribution of vapor mixing ratio around the eye of the typhoon is quite asymmetric, in all the experiments the eastern part of the center of the typhoon where the eyewall is still in the sea during the typhoon's landfall is greater than the western part of the typhoon where the eyewall is in the land. The western part of the center of the typhoon has a discontinuous spatial distribution because the cloud structure is broken under the influence of the topography. Regarding the upstream in a typhoon, the east area of the center of the typhoon, where the eyewall of the typhoon is still at sea, has a higher value than the west because the east of the typhoon is still supplied with heat and moisture from the ocean. Updraft in high topography altitude experiment also higher than those in low topography altitude. Thus, at the time of landfalling, the topographic elevation plays a role in increasing the low-level wind speed and the updraft speed in the typhoon.

3.2.2 The role of topography in typhoon intensity



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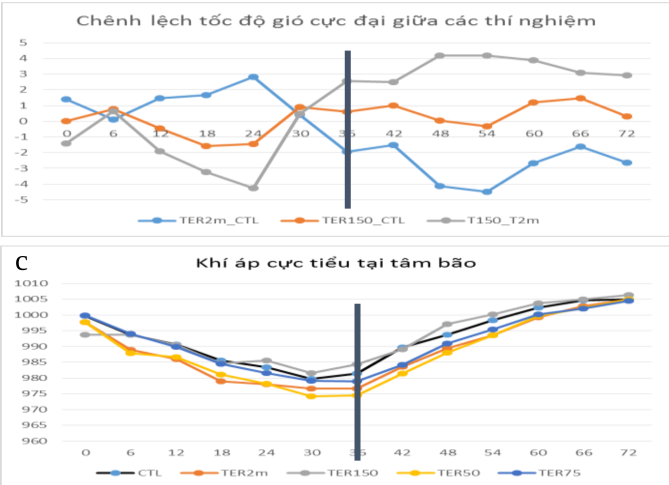
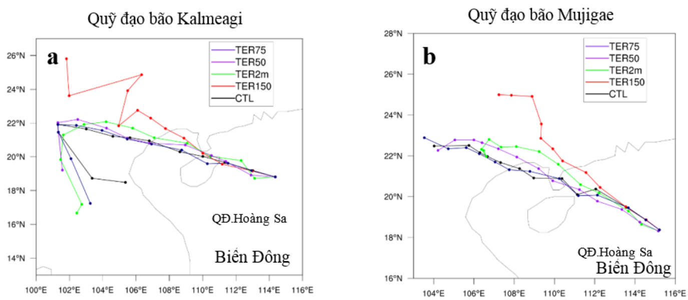


Figure 3.20: maximum wind speed at 10-meter level (a), maximum wind speed difference (b), minimum pressure at the typhoon center (c) in cases of CTL, TER2m, TER150 and TER50, the black line represents the time of the typhoon's landfall.

3.2.3 The role of topography in typhoon track

Research results show that 4 out of 5 tropical cyclones have tracks deviating to the north and 01 typhoon (Damrey) has track deviating to the south when increasing the topography altitude. According to Figure 3.20, tracks of two tropical cyclones (Usagi and Wutipan) deviate to the south when the topography altitude decreases. Two tropical cyclones landfalled in the northern region, the track tended to deviate to the northeast in all experiments.



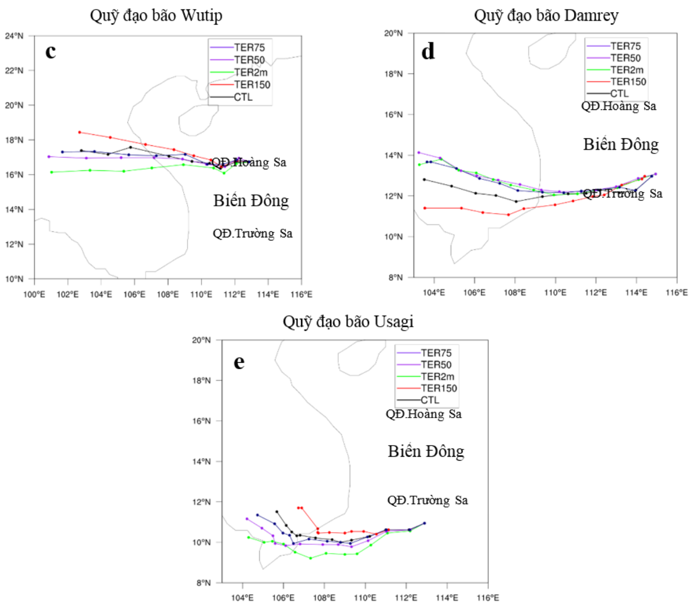


Figure 3.21: Tracks of typhoons (a) Kalmeagi, (b) Mujigae, (c) Wutip, (d) Damrey and (e) Usagi in the cases of CTL (black line), TER2m (green line), TER150 (red line) and TER50 (purple line) and TER75 (blue line)

3.3 THE ROLE OF COLD SURGE IN TYPHOON STRUCTURE

To examine the role of cold surge on the structure of some meteorological fields in tropical cyclones, the thesis proceeds in two directions. The first direction is to build integrated typhoon vortex to see the change of typhoon vortex structure in the presence of cold surge on the basis of statistical data from a relatively large number of cyclone cases. The second approach is high-resolution simulation of some typical tropical cyclones in order to study in more detail the role of cold surge on the structure of some meteorological fields in the typhoon.

3.3.1. The role of cold surge in the integrated typhoon vortex structure

Figure 3.22 shows the result of integrating the average structure of the rainwater mixing ratio field (kg/kg) in the typhoon. In all cases, it can be seen that the common feature is that the rainfall area is concentrated in the south and southwest of the typhoon center because the moisture-rich air from the south was brought into the eyewall. Thus, cold surge increases the rainfall area in the northwest of the typhoon vortex. This rainfall area is associated with enhanced moisture convergence due to this northern eyewall interaction with the monsoon could increase northwest precipitation of the typhoon, when the typhoon makes landfall under conditions of winter monsoon activity.

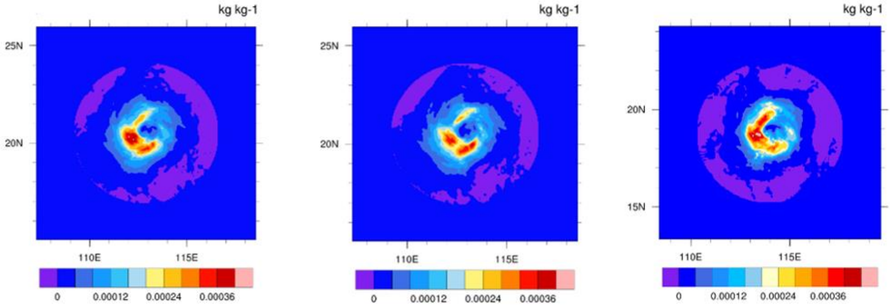


Figure 3.22: Rainwater mixing ratio field at surface level (kg/kg) average of 18 tropical cyclones (a), tropical cyclones not affected by cold surge (b) and tropical cyclones affected by cold surge (c).

Figure 3.23 shows the integrated image of the average structure of the wind speed field (m/s) at 10 meters level. The results show that the strong winds are concentrated to the east and north of the typhoon center in the case of integrating all 18 selected tropical cyclones (Figure 3.23a) because this part has little friction with the topography. A decrease in the western wind speed of the typhoon eyewall due to the effect of topographical friction is most pronounced when typhoon makes a landfall. In the case of integrated cyclones not affected by the cold surge, the strong wind area is also concentrated to the east and north of the typhoon center and the weak wind speed area is in the southwest where it is adjacent to the topography. The clear difference is shown when tropical cyclones affected by cold surge. An area of strong northerly and northwesterly winds is strengthened with a maximum speed of 2-6 m/s greater than the case not affected by cold surge. It can be seen that gas particles with relatively high momentum in cold surge contribute to wind speed enhancement (possibly leading to an increase in maximum wind speed in tropical cyclones) in the northern and northwestern eyewall of the cyclone.

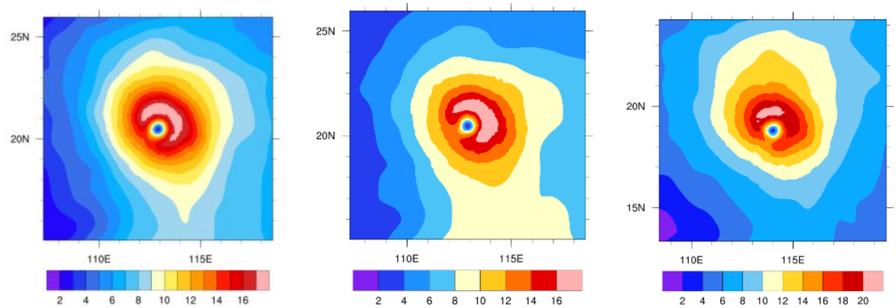


Figure 3.23: The average 10m (m/s) level wind speed field structure of 18 tropical cyclones (a), tropical cyclones not affected by cold surge (b) and tropical cyclones affected by cold surge (c)

3.3.2 Damrey typhoon

Based on the relatively good prediction of the intensity as mentioned in Section 3.1, the model product running with vortex initialization is used to make judgments about the vertical structure of the typhoon near the shore and landfalling. The satellite cloud image in Figure 3.26b shows that, when it was about 400 km from the mainland, the typhoon size was quite large with a relatively symmetrical cloud structure near the center of the typhoon. However, deep convection in the east of the typhoon center is stronger than that in the west. The area with radius of over 200 km from the center of the typhoon has an asymmetrical structure with clouds concentrated in the north of the typhoon center. In the east of the typhoon, clouds are mainly concentrated in an area about 200 km near the center. The asymmetrical distribution characteristics of clouds are simulated relatively well by using model.

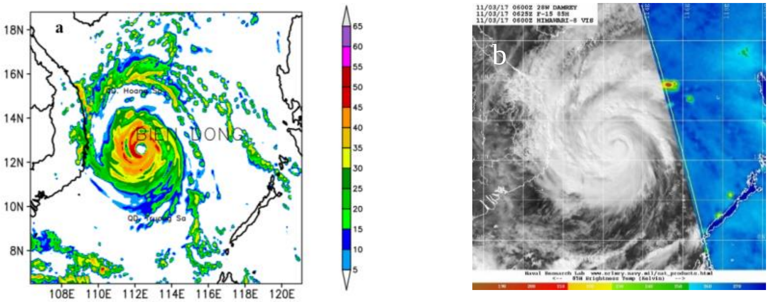


Figure 3.26: Radar reflextivity map with 6-hour forecast period with initialization (a) and satellite cloud image (b) at 06Z on November 3, 2017

The results show that while the sea-level pressure has a relatively symmetrical structure, wind distribution at 10meters level, the wind speed, and the convergence mixing ratio have strong asymmetrical characteristics with values towards the west. As the typhoon approached the shore, the structure continued to maintain strongly asymmetrical with strong winds and strong convection. This feature is quite unusual for Damrey because in this case, the west eyewall of the typhoon had a wind direction roughly in the same direction as the northeast monsoon, leading to resonances and strong winds. To the north, far from the center of the typhoon, clouds intensify was enhanced by moisture convergence when the typhoon circulation interacted with cold surge. When the typhoon made landfall in Vietnam, the west area of the typhoon with deep convection developed due to the interaction between the typhoon circulation and the topography. In contrast to convection, the maximum wind speed at 10 meters level in the landward, although at higher altitude up to 2 km, is much weaker than the maximum wind speed at sea due to the strong impact of surface friction and the attraction of air with weak kinetic energy inland into the area near the center of the typhoon.

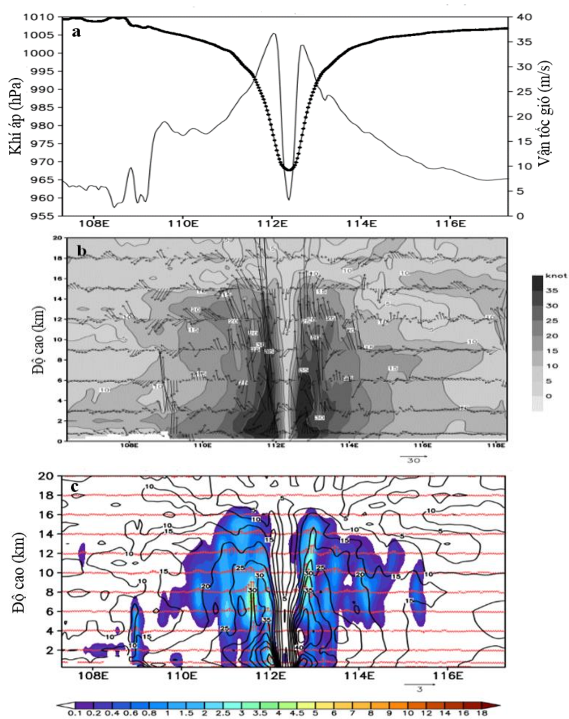


Figure 3.27: Vertical section through the center of typhoon in case of vortex initialization for (a) wind at 10 meters level (solid line, m/s), sea level pressure (dotted line, hPa), (b) wind (vector) and wind speed (color) and (c) comvergence mixing ratio (color) at 06 hr forecast at 06Z on November 3, 2017

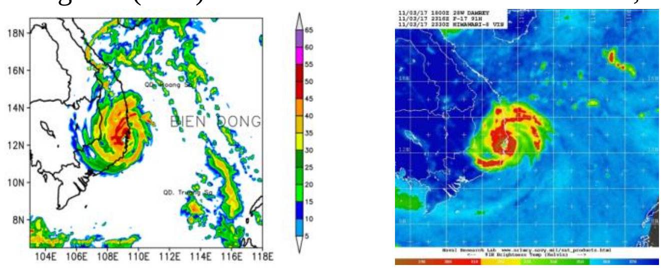


Figure 3.29: Radar reflextivity and satellite cloud image at landfalling stage (a) 24-hour forecast at 00Z on November 4, 2017 and (b) satellite cloud image on November 3, 2017.

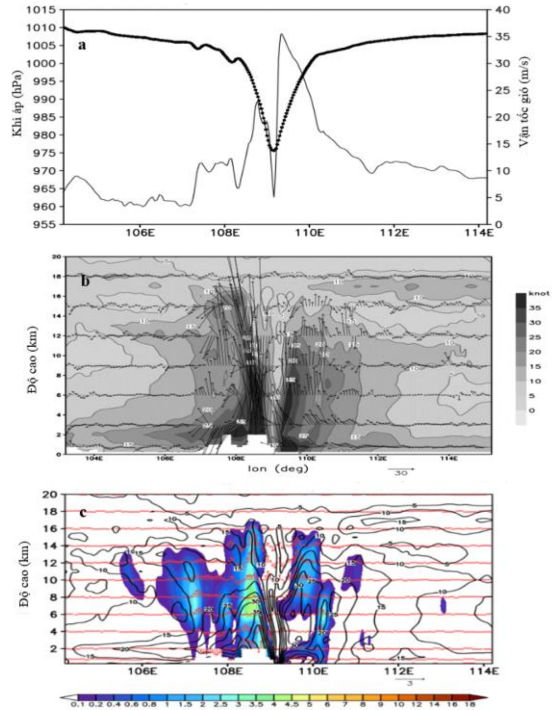


Figure 3.30 Similar to Figure 3.27 but for a 24-hour forecast time 00Z on November 04 , 2017.

3.3.3 Mujigae typhoon

In the case of Mujigae typhoon (2015), observation of typhoon intensity showed a significant difference (up to 10 m/s) between the data at JTWC and JMA. The high uncertainty in typhoon intensity observation may be one of the important reasons why the quality of typhoon intensity forecast in the world has not improved significantly in recent decades. After vortex initialization, the minimum sea level pressure is deepened and the maximum wind speed is enhanced. The simulation of the deep convection cloud structure is suitable with reality, the distribution of wind strength near the typhoon center is also more suitable, the eye radius is closer to reality, and the track error of all models up to 24 hr are all less than 50 km.

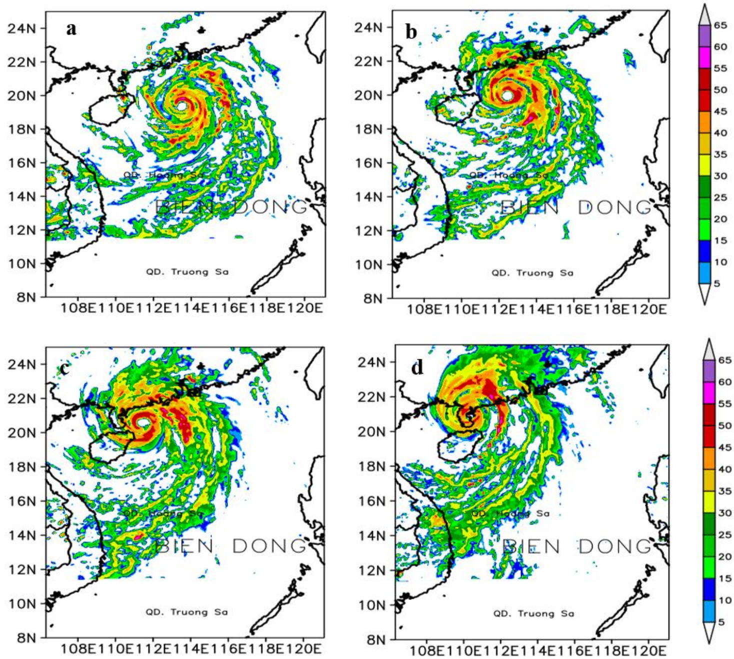


Figure 3.31: Radar reflextivity simulation at (a) 12Z October 3, 2015, (b) 18Z October 3, 2015, (c) 00Z October 4, 2015 and (d) 06Z October 4, 2015 from initialization.

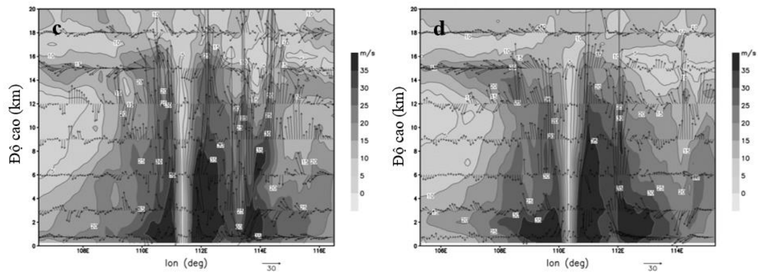


Figure 3.32: The east-west vertical section through the center of the typhoon for the wind speed (color coated, m/s) and the wind vector at the grid point according to the simulation with initialization at (a) 12Z 03/10/ 2015, (b) 18Z October 3, 2015, (c) 00Z October 4, 2015 and (d) 06Z October 4, 2015.

The analysis of the model product with vortex initialization showed that the Mujigae eyewall structure has strongly asymmetrial. When tropical cyclones are at sea, the wind zone is stronger in the east due to main reasons such as: (1) strong convection in this area helps to bring gas particles with high kinetic energy at lower level to higher, (2) wind gradient enhanced by the interaction between the typhoon eyewall with the continental cold high pressure in the north of the typhoon and (3) small sea friction. When the typhoon made landfall, the difference in Mujigae was that the northern part of land where there was a strong effect of land friction had stronger winds than that in the sea part where the friction effect was weak. This anomaly may be due to the wind in the northern part of the typhoon enhanced by the strong gradient wind when there is an activity of the northern continental cold high pressure.

CONCLUSIONS AND RECOMMENDATIONS

I. CONCLUSSIONS

By using the weather forecasting and research model (WRF), the thesis has studied the influence of topography, cold surge on typhoon structure in coastal areas of Vietnam. The thesis has achieved some results as follows:

1) The thesis has built a system of 04 experiments increasing and decreasing topography elevation and initialization programs to improve the quality of the initial field, then used the best initialization scheme to study the structural simulation of tropical cyclones under interaction with cold surge.

2) Topography experiments were carried out with 05 tropical cyclones operating under the influence of winter monsoon. The research results showed that the topography has a clear impact on the structure of meteorological fields in the typhoon, the track and intensity as well. As follows:

- When decreasing the topography altitude, the structure of the meteorological fields in the typhoon is more symmetrical than in the case of increasing the topography altitude.

- Typhoon intensity in the case of decreasing topography elevation is larger than the default case and topography elevation increase.

- In the case of increasing topography elevation, the typhoon track is deviated to the north compared to the actual in most tropical cyclones, apart from Damrey typhoon, the track is deviated to the south.

3) Research on the influence of cold surge on typhoon structure showed the followings for tropical cyclones from the East Sea entering the Central region under the impact of cold surge:

- When the typhoon approached the shore, the typhoon structure had strongly asymmetrical features with stronger winds and stronger convection towards the mainland because the westward circulataion of the typhoon has a wind direction roughly coincident with the northeast monsoon, resulting in a resonance that makes the wind stronger. To the north, far from the center of the typhoon, clouds intensify enhanced by moisture convergence as the typhoon eyewall interacted with the cold surge. When the typhoon makes landfall, the maximum wind at 10 meters level was strengthed in the landward due to the strong influence of surface friction and the attraction of the air with weak kinetic energy inland area to the area near the center of the typhoon.

- In case the typhoon tends to shift to the north in the strong winter monsoon conditions, the typhoon has strongly asymmetrial. When tropical cyclones over the sea, stronger winds are located in the east because strong convection helped to bring gas particles with high kinetic energy at low levels to higher levels, and wind gradients are enhanced by the interaction between typhoon circulation and a cold north continental high pressure under the small sea friction conditions.

- When the typhoon makes landfall, the land in the north of the typhoon where there is a strong effect of friction, has stronger winds than that in the sea with the small frictional effect. The reason for this anomality is the activity of the cold north continental high pressure causing stronger wind gradients to strengthen winds in the northern part of the typhoon.

II. RECOMMENDATIONS

Typhoon is a very complex dynamical system in the atmosphere. The study and assessment of the influence by simultaneously changing the altitude of the topography and the intensity of cold surge has not been carried out in the thesis because cold surge is a moving system, the thesis has not done the change of cold surge intensity in the simulation model. In further studies, it is necessary to study the changes in the intensity of cold surge in experiments to better understand the simultaneous effects of cold surge and topography on typhoon structure.

Research on the role of the ocean-atmosphere interaction in the cold-air typhoon interaction using combined sea-atmosphere modeling systems as well as the enhanced typhoon observation data in the East Sea to make clear the influence of cold surge on typhoon structure, intensity is also a research direction that should be paid attention.

LIST OF PUBLICATIONS RELATED TO THE THESIS

1) Dang Hong Nhu, **Nguyen Binh Phong**, Nguyen Xuan Anh, Nguyen Dang Quang, Nguyen Van Hiep (2017), "The Role of Orographic Effects on Occurrence of the Heavy Rainfall Event over Central Vietnam in November 1999", Science Magazine and Technology, Vol.17, No.4B, p. 31-36.

2) **Nguyen Binh Phong**, Nguyen Tien Manh, Nguyen Van Hiep, Nguyen Van Thang (2018), "Research and application of NC2011 vortex initialization scheme in WRF model to investigate the ability to predict the intensity of typhoon Damrey in 2017", Journal of Meteorology and Hydrology, 688, pp. 9-23.

3) **Nguyen Binh Phong**, Nguyen Anh Quoc, Nguyen Van Thang, Nguyen Xuan Anh, Nguyen Van Hiep (2019), "Study on interaction between cold surge and tropical depression during heavy rain from October 13 to 16// 2016 in the Central Region of Vietnam", Journal of Science of Natural Resources and Environment, 27, p. 14-26.

4) **Nguyen Binh Phong**, Nguyen Tien Manh, Nguyen Xuan Anh, Pham Le Khuong, Nguyen Duc Nam, Pham Xuan Thanh, Nguyen Van Hiep (2020), "Initial application of vortex simulation and structural study of Mujigae typhoon (2015) nearshore and made landfall", Journal of Hydrometeorology, 709, p. 1-12.

5) **Nguyen Binh Phong**, Nguyen Van Hiep, Nguyen Van Thang (2020), "Application of dynamic vortex initialization diagram to predict intensity and study structure of typhoon Damrey (2017) in nearshore and landfall phase", Journal of Climate Change Science, 16.