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STUDY OF ASSESSMENT AND PREDICTABILITY OF STORM ENERGY IN THE VIETNAM EAST SEA

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SUMMARY OF THE THESIS
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INTRODUCTION

1. Rationale

The storm energy indicators reflect the general trend of potential activity of storm season and they are additional information on storm numbers and days in predicting trends of storm season. They are being used quite commonly in storm predicting such as in the US, UK, etc. This term is also widely used in the fields of insurance, securities, and financial investment related to disaster risks. Real-time accumulated cyclone energy information combined with storm prediction including accumulated cyclone energy, number of storms, intense stroms and duration of storms is used to make business review or to prepare plans for management risks of storm.

Researching storms in the Vietnam East Sea (VES) has been interested by scientists, however there has been no in-depth study on the characteristics of storm energy as well as their prediction for the VES. Therefore, it is necessary to prediction of storm energy in order to add more information about storm activity in the VES.

2. Objectives

- Clarifying the characteristics of storm energy in the Vietnam East Sea and the relationship between storm energy in the Vietnam East Sea with sea surface temperature, and subtropical jet stream;

- Building statistical models to predict storm energy in the Vietnam East Sea based on sea surface temperature and subtropical jet stream.

3. Research subjects and scope

a) Research subjects

+ Storm and storm energy assessment index: Accumulated storm energy index (or accumulated storm kinetic energy, or storm wind energy);

+ Statistical features of storms, number of storms, intense storms, storm days: total, average, highest, lowest and other statistical characteristics.

b) Research scope:

The storm energy indicators and storm characteristics are considered in the Vietnam East Sea (0-23^{0}N, 100-120^{0}E);

c) Research Limits

+ Research has not had the conditions to analyze storm activity based on all storm energy indexes. This research is only using the accumulated cyclone energy index (ACE) in the Vietnam East Sea (VES). The study did not discriminate between storms forming in the Vietnam East Sea and storms from outside on VES. In addition, this research only analyzed the correlation between accumulated cyclone energy in the Vietnam East Sea with sea surface temperature, with subtropical jet stream but has not had the conditions to analyze the relationship with other features such as storm structure, sea topography or monsoon, etc.

+ Model to predict accumulated cyclone energy in the Vietnam East Sea is built based on the global prediction product of CFSv2 model. At the same time, based on the correlation between ACE in the Vietnam East Sea and the sea surface temperature (SST), with subtropical jet stream (APSJ). However, the study did not had conditions to consider other predictors.

4. Thesis statement

1) There are similarities and differences of storm energy in the Vietnam East Sea with the Western North Pacific basin and exists a close statistical relationship between accumulated cyclone energy in the Vietnam East Sea with sea surface temperature in the Southeastern Japan Sea and with the subtropical jet stream.

2) It is possible to use sea surface temperature in the Southeastern Japan Sea and the subtropical jet stream to predict the cumulatived cyclone energy index when close relationship of them is determined.

5. Research methods

1) To evaluate the characteristics of accumulated cyclone energy in the Vietnam East Sea and determine their relationship with other climatic

factors, the study used methods including analysis of geography, correlation, trends, empirical orthogonal functions and statistical tests.

2) In order to forecast storm energy in the Vietnam East Sea, the study uses the following methods: methods of single and multivariable linear regression analysis, testing statistics, assessing errors of prediction ment and evaluating the effectiveness and reliability of predictive equations.

6. Original contributions of the Thesis

- The study has determined storm energy in the Vietnam East Sea is similar to that in the Western North Pacific basin from July to November. The time of peak concentration of storm energy in the Vietnam East Sea is about 1 month later, tends to decrease during the period 1982-2018 and to increased in the two decades 1999-2018.

- The study has identified and partly explanied for the physical mechanism of the relationship between the accumulated cyclone energy in the Vietnam East Sea with the sea surface temperature in the Southeastern Japan Sea and the intensity of subtropical jet stream. This relationship is used as a scientific basis for seasonal predicting of the accumulated storm energy with leadtime about 1-2 months based on the product of the CFSv2 dynamic model.

7. Scientific and practical contribution of the Thesis

1) Scientific contributions

- The research results contribute to providing a scientific basis on characteristics of storm energy in the Vietnam East Sea and the relationship with SST in the Southeastern Japan Sea and APSJ;

- Research results can be used as a reference for storm researches in the Vietnam East Sea.

2) Practical contributions

- The research results contribute to the conclusion of lessons in the assessment of storm activity in the Vietnam East Sea based on the variable trend of SST in Southeastern Japan Sea and the intensity of APSJ;

- The results of the ACE prediction contribute to reflect the general trend of the potential activity of the storm season and provide additional information about the number of storms and duration of storm activity in the prediction of the storm season trend.

8. Structure of the Thesis

The main content of the thesis is presented in 4 chapters: Chapter 1: Overview of research on storm energy; Chapter 2: Data, predicting and evaluating methods of storm energy; Chapter 3: Assessment of storm energy and relationship with sea surface temperature, subtropical jet stream; Chapter 4: Applicability of SST in the Southeastern Japan Sea and subtropical jet stream to predict accumulated cyclone energy in the Vietnam East Sea.

Chapter 1: OVERVIEW OF RESEACH ON STORM ENERGY

1.1 Storm energy

The goal of the thesis is to apply energy index for the VES, therefore, the thesis is overview of the mainly research related to the storm energy index. The concept of "accumulated cyclone energy" (ACE) index was first proposed by Bell et al. (2000) [38], or "cumulatived cyclone kinetic energy" as Kim et al (2013) [86]; Lu et al (2018) [105] or “storm wind energy” (NOAA). The kinetic energy is proportional to the square of the velocity. The accumulated kinetic energy is the sum of kinetic energies over some time interval. This shows that storm has strong wind intensity, prolonged duration lead to higher ACE. Similar to ACE, Emanuel (2005) [62] proposed the PDI index to be expressed as a cubic function of wind speed. Yu et al (2009, 2012) [145], [146] suggested that ACE and PDI have high weights for intense storm, therefore they proposed to adjust ACE, PDI to reduce weights. ACE and PDI are corrected by adding radius and called RACE and RPDI. To further support the Saffir-Simpson scale, Kantha et al. (2006) [82], Powell et al (2007) [109] have proposed IKE “integrated kinetic energy”.

However, data sources for calculating IKE are not available for the Western North Pacific basin (WNP).

In general, the storm energy indexes:

- The storm energy indexes are only calculated for tropical cyclones reaching tropical storm intensity, the method does not depend on the time step and they are useful in correlation and regression calculations as well as suitable for assess the influence of climate variables on storm intensity;

- The storm energy indexes will add information about the intensity and lifetime of the storm. During the storm season, there are some intense storms, the number of active days is long, leading to a higher accumulated storm energy, so the risk is greater than in the storm season with many weak storms and with shorter lifetime.

- The calculation methods of RACE RPDI, HDI and TIKE is more complicated than ACE, PDI because they need to add the storm radius.

1.2 Storm energy in the seas and storms in the VES

1.2.1 Characteristics of storm energy over sea areas

The storm energy indexes are not only applied to assess the characteristics of storm in the great Ocean, but also for sub-regions such as Taiwan, Bay of Bengal, Arabian Sea, etc.. In fact, the storm energy index is widely applied in the fields of insurance, securities, and financial investment related to disaster risks. Real-time cumulative storm energy information combined with predicting of storm numbers and days will used to develop resource preparedness plans for storm risk management..

The storm energy index reflects “total overall seasonal activity", refers to the combined intensity and duration of named storms occurring during the season; During the storm season, there are some very intense storms, the number of active days is long, leading to a higher energy, so the risk of impact is greater than in the season with many weak storms, with shorter lifetime. Thus, the storm energy index is very important in generalizing to include the number, intensity and lifetime of storm. This is the scientific basis for monitoring and predicting of storm in the VES.

1.2.2 Characteristics of storms in the VES

Many studies are interested in researching and evaluating storms in the ES, but mainly based on number of storms. Storm energy has also been studied since 1991 with the aim of analyzing the structure and determining the criteria for the development of the storm in the VES.

1.3 Relationship between SST, APSJ with storms in the Western North Pacific basin and storms in the VES

Previous studies have shown the influence of ENSO on storms in the WNP related to SST, summer monsoon troughs, etc. At the same time, many studies show that SST is one of the important factors not only directly affect but also indirectly affect to storms in the WNP and the VES through large-scale atmospheric circulation. In a number of different large-scale systems in the WNP, studies also shown that APSJ are closely related to weather and climate in East Asia, SST, and storms in the WNP and the VES. In addition, summer "wave train" or differences in convection activity over the Philippine Sea and the Sea of Japan known as the Pacific-Japan Pattern (P-J). P-J pattern can significantly influence on storm variability in the WNP. Many researches show that the P-J pattern has been related to the “waveguide/duct” established by the summer monsoon or the "bridge" of the southwesterly affecting to weather, climate in East Asia and active storm in the WNP.

1.4 Seasonal range prediction for storms and storm energy

Many agencies predict ACE and the number of storms such as NOAA, TSR, CSU, IRI, etc. Methods of statistical and numerical models have been applied to seasonal predicting for ACE and number of storms. In Vietnam, the application of seasonal predicting research has achieved certain results. This is applied to predict the 3 months about the storms and tropical depressions numbers in the VES from IMHEN. Simultaneously prediction of the storm and tropical depression numbers from the National Center for Hydro-Meteorological Forecasting. However, no study for ACE predicting in the VES has been published.

1.5 Summary of chapter 1

Storm energy indicators will supplement about the intensity and duration of storms and they can be used to assess the risk of storm season. The reality shows that real-time monitoring and predicting of storm energy is additional information for storm analysis such as in the US, UK, Japan, etc. This term is also used widely in the fields of insurance, securities, financial investment related to disaster risk. The storm energy index has been widely applied in the large Ocean and sub-sea regions. However, there have not been many in-depth studies and predicting of storm energy in the VES. In this regard, how does storm energy variation in the VES. What are the similarities or differences in storm energy in the ES compared to the WNP.

Studies shows that the influence of SST and large-scale circulation such as North Pacific subtropical high pressure (NPSH), or APSJ on storm activity in the WNP basin and the VES. However, which SST in the seas and large-scale circulations is closely related to the storm energy in the VES has yet to be determined. The similarities or differences of the storm energy in the VES and the WNP have a relationship with the SST and SST in any sea is closely related to storm energy. Is the APSJ as a large-scale circulation regarding this relationship. If the close relationship with storm energy in the VES can be determined, can it be used as a predictor to predict storm energy.

Chapter 2. DATA, PREDICTING AND EVALUATING METHODS OF STORM ENERGY

2.1 Data

2.1.1 Storm data

All storm statistics in this study are based on storm data from the Japan Meteorological Administration (JMA) and from Joint Storm Warning Centre

(JTWC). The storm energy indexes aim to add more information to the storm system, so the thesis only considers tropical cyclone reaching tropical storm (exceeding 17 m/s according to Beaufort). A comparison between storm and intense storm including all tropical cyclone with the maximum wind speeds exceeding 32.5 m/s (category 12 and above) will also be considered.

2.1.2 Sea surface temperature and reanalysis data

1) SST data (ERSST.v4) with 2^0 x 2^0 resolution from NOAA was used for the analysis of effects on storm activity.

2) Atmospheric data from NCEP/NCAR Reanalysis 1 and NOAA for analyzing the influence of the environment on storm activity.

2.1.3 Data of climate forecasting system version 2 (CFSv2)

1) Re-forecast data for the period 1982-2010 is used to establish the equation for predicting ACE from May-Dec and Aug-Dec.

2) Operation data of CFSv2 period 2013-2018 are used as independent data for error assessment of ACE prediction

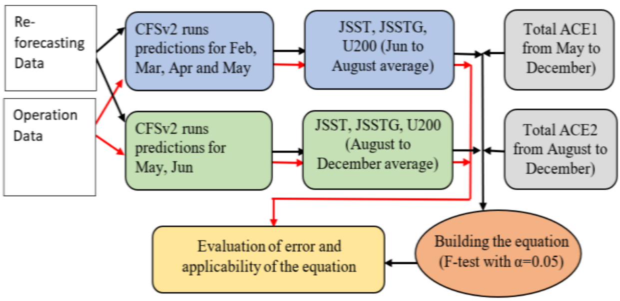


Figure 2. 1. Descriptive diagram of data collection for the building of the predictive equations of ACE in the VES

2.1.4 Data on seasonal storm prediction of some professional agencies

In order to compare and evaluate the feasibility of the ACE predicting equations in the VES, the thesis collects data at some world's professional prediction agencies about ACE, specifically about the data:

1) Predicted and observed ACE data for the period 2003-2018 in the

Atlantic basin of CSU, CPC and TSR compiled by NOAA.

2) Summarized data on prediction of ACE for the WNP basin in March, May, July and August in the period 2003-2010 and 2013-2014 from TSR

2.2. Research Methods

2.2.1 Calculation method of accumulated storm energy indexes

Research scope: *the Vietnam East Sea area (0-23°N; 100-120°E).*

1) The thesis has presented a method to calculate storm energy indexes including ACE, PDI, RACE and RPDI index, storm days (NCB). ACE and PDI use the maximum wind speeds around the center of the storm. RACE and RPDI need to add storm radius and establish a relationship to determine the coefficient (α), this study used the coefficient α=0.51 on the WNP basin according to Yu et al (2009, 2012) [145], [146].

2) Storm energy indicators will supplement information about the intensity and duration of the storm. In the storm season there are many intense storms, the number of active days is long, leading to a higher accumulated storm energy, so the risk of impact is greater than in the season with many weak storms, with shorter duration.

2.2.2 Analysis method of storm trend

The linear trend is used to survey the changing trend of storm characteristics in the VES, the coefficient (b1) of the single linear regression over time shows the nature of the increasing or decreasing trend, absolute value of b1 shows the change level. Assess the reliability of the trend based on Student's test for (r) [25], [26], [21].

2.2.3 Methods of correlation analysis and comparison of two expectations

- The correlation coefficient (r_{ij}) is used to measure the linear relationship between y and x variables. In there, y variable is storm characteristics and x is the value field of environmental factors (variable x) identified on each grid point (i, j in there i, j are the latitude and longitude). Set of grid points with r_{ij} will show the relationship between large-scale environmental variables with storm characteristics.

- The study uses Student's test for the magnitude of r_{ij} to evaluate the statistical reliability of the relationship between environmental factors and storm characteristics [5], [21].

- The study uses the method of comparing two expectations to consider the mean difference with unequal variance of two data series x_{1ij} (average environmental factor in high ACE years) and x_{2ij} (average environmental factor in low ACE years) per grid point (i, j are the latitude and longitude). At the same time, Student's test is used to assess the statistical reliability of this difference (Vu Van Thang, 2016 [27]; Wilks et al., 2006 [135]).

2.2.4 Principal component analysis method

For principal component analysis defined over the longitude/latitude domain (25-60^{o}N, 80-150^{o}E), with up to 37 eigenvectors (EOFx) and principal components can account for more than 99% of the total variance. PCA was applied to the U200 mb to search for empirical functional structures to the dominant variation for the definition of shift and intensity of APSJ.

2.2.5 Seasonal range predicting method for storm energy

a) Mathematical basis of linear regression

The detailed mathematical methods of single and multi linear regression are presented in the textbook of authors Phan Van Tan (2007) [20], author Hoang Duc Cuong and Nguyen Trong Hieu (2012) [4].

b) Evaluation of the quality of the regression equation

To evaluate the quality of the regression model, the thesis uses Fisher's test method with significance level α=0,05 (Phan Van Tan, 2007 [20], Hoang Duc Cuong and Nguyen Trong Hieu, 2012 [4]).

e) Equation evaluation criteria

The statistical-dynamic equation is evaluated for quality based on the criteria of mean error, mean absolute error, squared error, mean squared skill score and predictive evaluation in two phases (Nguyen Van Thang et al., 2010 [24]; Hoang Duc Cuong et al., 2013 [5]; Phan Van Tan et al., 2010 [21]; Tran Quang Duc et al., 2020 [8])

Chapter 3. STORM ENERGY ASSESSEMENT AND RELATIONSHIP WITH SEA SURFACE TEMPERATURE, SUBTROPICAL JET STREAM

3.1 Storm characteristics based on storm energy index

3.1.1 Assessment of the storm energy in the WNP and the VES

a) Annual assessment

The most active storm season in the VES appears to start significantly earlier in June and maintains during the entire June–November period, whereas the most active period in the WNP basin is the period of July–October. The peak time of storm energy in the WNP basin is around August-September, whereas in the VES it is around September-October (about 1 month later). The distribution of the number of storms is also significantly different compared with the storm energy indexes in the VES; The distribution of storm numbers is uniform from July-October with a peak in August-September, whereas the peak of the storm energy index is later about 1 month (September-October). In general, the annual variation of the storm energy indexes has little difference and is quite similar to the intense storm and the duration of the storms.

b) Inter-annual assessment

Inter-annual variation between storm characteristics in the Vietnam East Sea and the WNP are also significantly different. Inter-annual variation of the storm energy indexes has little difference and is quite similar.

The ACE and PDI indexes are of more interest because of their higher weighting for intense storms, greater attention to their impact risk. The method of calculating RACE, RPDI index is more complicated than ACE, PDI and they have not been widely applied. At the same time, variability of RACE and RPDI is little difference with ACE and PDI. In fact, ACE is being widely applied in research as well as predicting. In addition, they are being widely used in the fields of insurance, securities, financial investment related to risks caused by disasters. In order to focus the analysis further, therefore the study used ACE for the following analyses.

3.1.2 Assessement of ACE in the VES

a) Characteristics of ACE in the VES

The average number of storms per year is about 9-10 storms (high years is about 14-16 storms; in years of strong/week storm activity, called high/low years). The standard deviation of the number of storms is about 2.9-3.0 storms and the coefficient of variation is about 31-32%. The average NCB in is about 34-38 days (high years is about 62-67 days, low years is about 13-17 days). The average ACE is about 76-80 $x10^3m^2s^{-2}$ (high years about 140-160 x $10^3m^2s^{-2}$, low years is about 15-20 x $10^3m^2s^{-2}$). ACE standard deviation is about 32-35 x $10^3m^2s^{-2}$ and coefficient of variation is about 42-45%.

Analysis of typical high ACE years showed that each year of high ACE was significantly different and there were not find a consistent pattern in the distribution of monthly variables. It also clearly shows the role of high-weighted of intense storms in the magnitude of ACE. Although the relationship between ACE with the number of typhoons from 8-11 level is not high, the number of storms and NCBs is quite high (correlation coefficient is about from 0,56-0,77). This shows that it is possible to build the equation to estimate the number of storms and NCBs based on ACE.

b) Linear change trend of storm in the VES

The trend of storm and ACE is decreasing in the period from 1982-2018 and increasing in the two decades from 1999-2018, which is quite consistent on data of JMA and JTWC, but does not reach 95% statistical confidence. .

c) Spatial distribution of storm in the VES

On the grid of 2.5^0 x 2.5^0 in the Central coast from about 16^0N - 18^oN and the North of Vietnam coast (north of 20^oN) have number of storms and ACE are highest in the coastal range of Vietnam.

3.2 Relationship of SST in Southeastern Japan, intensity of subtropical jet stream with ACE in the Vietnam East Sea

3.2.1 The relationship between SST with ACE in the Vietnam East Sea

a) Direct influence of SST

Previous studies have shown that SST directly affects storm activity (Camargo et al., 2005 [43]; Richard and Zhou 2014 [111]), thus this research will investigate the direct effect to storm activity in the VES. The sensitivity survey shows that focusing on the period from June to November helps to maximize the statistical signal in the VES and will be presented in the following analyses. Storm activity in the WNP can contribute to clarifying storms in the VES, in order to have a general picture of storms, so in this section, storms in the WNP will also be considered. The results show that:

1) For storm characteristics in the WNP including the number of storms, storm above 12 level (typhoons and intense typhoons), ACE and NCB: Positive correlation between SST in the central Pacific region and storm characteristics in the WNP basin. This shows that the higher SST in central Pacific will correspond to higher storm characteristics in the WNP basin. In contrast, the significant negative correlation between storm characteristics with SST in the Indian Ocean and Southwestern Pacific shows that higher SST in these regions will correspond to lower storm characteristics in the WNP. This negative correlation is likely related to increased summer vertical wind shear as shown by Zhan and Wang (2015) [155].

2) For storm characteristics in the East Sea (C8, C12, ACE, NCB): In contrast to storm in the WNP basin, there is a negative correlation between storm characteristics and SST in the central Pacific. This shows that higher SST in the central Pacific corresponds to fewer storms in the VES. This can be explained that storms in the VES is mainly depend on large-scale flow related to the NPSH. So there could be more storms in the WNP, but maybe fewer storms in the VSE. This is also one of the reasons for the negative

correlation in the VSE. In addition, years of high SST in the central Pacific, an anticyclone in the Western Pacific basin and the VES with adverse environmental conditions have limited storm activity in the VES as indicated by previous studies (Figures 1.11 to 1.14 and 1.16 in chapter 1).

b) Indirect influence of SST

The direct influence of SST on the storm intensity in the WNP basin as established previously from both theoretical and numerical modeling studies (Sun et al., 2013 [119]; Ferrara et al., 2017 [67]). Indirect effects of SST have also been shown to be important, especially in the WNP basin as pointed out by Richard and Zhou (2014) [110]; Li et al (2017) [98]. This is because SST is involved in the first-order response of large-scale atmospheric circulations in the WNP basin, which can indirectly affect storm intensity.

ACE in the VES was significantly negatively correlated with SST in three main regions, including the Indian Ocean (5^{o}S-10^{o}N × 70^{o}E-88^{o}E), the Southwestern Pacific Ocean (41-27^{o}N × 155-170^{o}E), and the Southeastern Japan Sea (25^{o}N-35^{o}N × 139^{o}E-160^{o}E), the SST symbols are ISST, SSST and JSST respectively. Among the three regions, JSST has the highest correlation coefficient. Based on the years of the high (low) JSSTG (the difference between the JSST and the SST in the central WNP warm pool) shows that when the JSSTG is higher, there are fewer storms in the VES. Subsequent analysis showed that during the high ACE year, the Tibet high pressure shifted towards the poles and moved eastward; NPSH shifted more to the west; Geopotential height of 500mb and 850mb levels tend to be high in the sea Eastern of Taiwan and low in the East of Japan Sea. This has shown (P-J) pattern as indicated by previous studies. The relationship between JSSTG with storms in the VES will be analyzed in the following sections.

3.2.2 The relationship between the APSJ with ACE in the VES

The influence of SST in the Southeastern Japan Sea on the ACE in the VES suggests that a potential factor explains the variability of storm activity in the VES. Among several large-scale systems in the WNP basin such as monsoon or NPSH, previous studies have shown that the APSJ is closely related to weather, climate in the East Asia and SST.

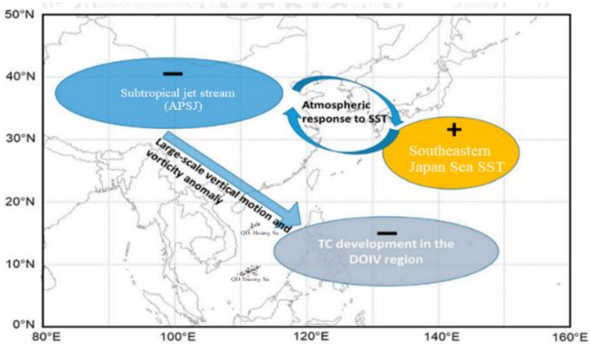
Wind analysis at 850 mb and 200 mb during the high/low ACE years in the VES shows a low ACE year (high JSSTG), high level cyclone (200mb) and low level anticyclonic (850mb), Weakly developed convection, less relative vorticity at low level and weak upper divergence in the VES and Eastern Philippines Sea, detrimental to storm activity in this area, thus the ACE decreases over the East Sea. Reverse process for high ACE year (negative JSSTG year). It can be seen that these results of the wind anomaly analysis describe the same dipole pattern of SST distribution between the Indian Ocean, the central-east equatorial Pacific as compared to the central WNP warm pool. This wind anomaly is the same as the P-J pattern related to limited (development) convection in the Eastern Philippine Sea. This problem, previous studies shown the SST in the central WNP warm pool related to the change in energy, momentum between the ocean-atmosphere, or the sea-air interaction. These changes relate to large-scale atmospheric circulation changes, leading to environmental conditions that are unfavorable/favorable for storm activity (Figures 1.11-1.14, 1.16 chapter 1).

Because the distribution of the eigenvectors is roughly similar to the true distribution of the 200 mb zonal wind, PC1 and PC2 are considered as measures of the position and intensity of the APSJ. A positive (negative) PC1 would indicate that the APSJ changes position to the south (north). A positive PC2 indicates an increase in wind speed relative to APSJ, which is indicative of a higher intensity of APSJ (Lin et al., 2005, 2010) [100], [101]. Therefore, PC1 and PC2 were used for the follow-up evaluation. The position and intensity of APSJ were also determined by other methods (Yan et al., 2019 [143]; Huang et al., 2014 [75]) to further demonstrate the role of PC1, PC2.

The results show that the correlation between the storm's characteristics with PC1 is quite low, but with PC2 the statistical confidence is 95%. This suggests that the change in the position of the APSJ contributes little to the inter-annual variation of storms in the VSE, whereas the intensity of the APSJ plays a more role. At the same time, the APSJ intensity tends to connect more strongly to the JSSTG than to the APSJ site.

With changes in the low-level circulation over the VSE and Philippine Sea associated with PC2 variation, other large-scale conditions have to respond to changes in the large-scale circulation through the P-J pattern as well. (Nitta, 1987 [108]; Kubota et al., 2016 [91]). This P-J pattern is established to connect convection activity in the Eastern Philippines Sea and with large-scale circulations between the WNP and East Asia. Therefore, any variability in APSJ associated with JSSTG such as the correlation between PC2 and JSSTG also have an impact on storm activity in the VSE. This problem shows that during the high JSSTG year, high level easterly wind in the East Asia is associated with weaker APSJ, the subsequent response of large-scale atmospheric leads to weak vertical velocity, less relative vorticity in the VES and the Philippine Sea, it is unfavorable for storms in this area.

The results obtained from the above analysis provide an explanation for the effect of JSST on storm activity in the East Sea as part of the P-J pattern, which is summarized in a conceptual diagram in Figure 3.24. Consider, for example, an anomalously higher SST developed in the Southeastern Japan Sea. Subsequent response of the large-scale atmospheric to the change in JSSTG, leading to negative westerly wind anomaly in the East Asia (westerly winds the East Asia will be less enhanced), leading to the development of anticyclones at low level in the Philippine Sea. Together with convection in the VES and Philippine Sea is less enhanced, environmental conditions are less favorable for storms activity, so fewer storms enter the VES and reduce ACE. The process is reversed during the year JSSTG is below average and explains the negative correlation between JSSTG with ACE in the VSE. It is hard to attribute any causal interaction between SST and EASJ or provide any physical mechanism underlying the development of such a vorticity shown in Figure 3.14. However, the strong statistical relationship between PSD, EASJ, and ACE as found in this study could at least suggest a pathway that SST in the Southeastern Japan Sea can indirectly modulate TC activity in the VES that we wish to present here.



Hình 3.24. A conceptual diagram of the correlation between SST in Southeastern Japan Sea and storms in the AES. The APSJ intensity responds to JSST changes through large-scale dynamics, thereby influencing storms in the AES by enhancing or preventing large-scale vertical motion and vortex in the VES. The signs (-) represent the development of the negative anomaly corresponding to the anomaly (+) of JSST.

3.3 Summary of chapter 3

Although the inter-annual and annual ACE are somewhat similar to the number of storms, there are differences. On the grid 2.5^0 x 2.5^0, in the coastal area from about North of 20°N, the number of storms and ACE is highest in the coastal strip of Vietnam. The trend of storms and ACE decreased in the period 1982-2012 and increased in the period 1999-2018.

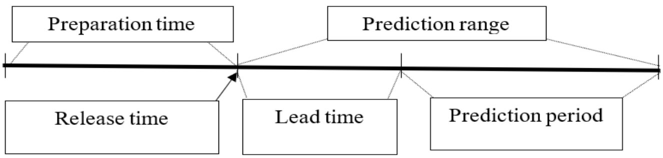
In the years of negative JSST and stronger APSJ, cyclonic at low level, anticyclone at high level, stronger vertical velocity and more relative vorticity, favorable for storm activity in the VES and Philippine Sea, thus increasing ACE in the VES. In this regard, the APSJ is considered to be the bridge between the JSST and the storm in the VES related to the proven P-J pattern. The reverse process for positive JSST and weaker APSJ.

Chapter 4. APPLICABILITY OF SST IN THE SOUTHEASTERN JAPAN SEA AND SUBTROPICAL JET STREAM TO PREDICT ACCUMULATED CYCLONE ENERGY IN THE VIETNAM EAST SEA

4.1 Set problem

The statistical equation to predict ACE will be built based on the predictors (NTDB), which is the re-forecast the global product of the CFSv2 dynamics model performed in the months of 2-6 for climate factors from May to Dec every year. In the operative prediction, the actual predicting products of CFSv2 will be used in the same period as the re-forecast.

In climate predicting, the relationship between the prediction period, lead time and the period of data preparation according to the diagram is shown in Figure 4.1: (1) Prediction time is effective prediction time; (2) Lead time is from the time the prediction bulletin is issued to the time prediction information is effective. Long-range prediction based on all data sources, up to the beginning of the prediction period, zero lead time; (3) The prediction range is the time sum of the prediction period and lead time.



(Source Hoang Duc Cuong et al., 2013) [5]

Figure 4. 1. Time graph in the seasonal range predicting

On the basis of research works on seasonal range predicting of storms, the thesis sets for the ACE test predicting as follows:

About prediction objects (ĐTDB): From May to Dec can be considered as the storm season in the VES and ACE tends to be high towards the end of the season, so equation building for ACE will be the total ACE from May-Dec (ACE1) and updated prediction from Aug to Dec (ACE2).

About predictors (NTDB): As discussed in chapter 3, there is a high correlation between ACE and SST in the Southeastern Japan Sea and APSJ intensity. Therefore, the thesis will apply those two features of CFSv2 implemented in Feb-June, period 1982-2010 as input for the process of building the predicting equations ACE1 and ACE2, specifically:

- The predictor is JSST, range is limited (210 - 31^{0}N, 145^o – 165+E) (orange rectangle in figure 4.5);

- The predictor is JSSTG: Difference between JSST and SST in the central WNP warm pool (0-15^{o}N, 125^{o}E-155^{o}E) (difference between mean SST in the orange and black rectangles shown in Figure 4.5);

- NTDB is zonal wind of 200mb over subtropical-East Asia (U200), the range is limited (350 - 45^{0}N, 90 - 115^{0}E) (black rectangle in figure 4.7).

Because the ACE is highly correlated with NTDB in summer as cited in chapter 3. Therefore, mean NTDB in summer (Jun-Aug) was used for the ACE1 prediction and average in Aug-Dec months for the ACE2 prediction.

On the basis of CFSv2 data and some climate predicting concepts cited in Figure 4.1, concepts related to seasonal range predicting for ACE1 and ACE2 are described in detail and cited in Figures 4.2 and 4.3.

a) For ACE1 prediction (Figure 4.2) (NTDB is JSST, JSSTG and U200mb are predicted by CFSv2 for Jun to Aug)

When CFSv2 is implemented in Feb: (1) The preparation time is about one and a half months (called 1 month) including 1 month for CFSv2 prediction in February, plus about 10-15 days for data processing; (2) Release time (TĐPT) of prediction is around March 10-15; (3) ACE1 prediction will be valid using from the beginning of May and end at the end of December, therefore the prediction period will be 8 months; (4) Lead time is about 2 months; and (5) Prediction range is about 10 months.

Similarly, when CFSv2 is implemented in March: The preparation time is about 1 month; TĐPT is around in April 10-15; prediction period is 8 months; lead time is 1 month; The prediction range is about 9 months. When CFSv2 is implemented in April: The preparation time is about 1 month; TĐPT around May 10-15; prediction period is 8 months; lead time is zero; The prediction range is 8 months. Finally, when CFSv2 is implemented in May: 1 month preparation time; TĐPT is about June 10-15; prediction period is 8 months; lead time is zero; forecast range is about 8 months.

a) For ACE2 prediction (Figure 4.3) (NTDB is JSST, JSSTG and U200mb are forecasted by CFSv2 for August to December):

When CFSv2 is implemented in May: (1) The preparation time is about 1 month (referred to as 1 month) including 1 month for CFSv2 prediction in Feb, plus about 10-15 days for data processing; (2) Release time (TĐPT) is around June 10-15; (3) ACE2 prediction will be using from the beginning of Aug and end at the end of Dec, therefore prediction time is 5 months; (4) Lead time is about 2 months; (5) Prediction range is about 7 months. Similarly, when CFSv2 is implemented in June: The preparation time is about 1 month; TĐPT is about July 10-15; prediction period is 5 months; lead time is 1 month; Prediction range is 6 months.

4.2. Relationship SST, U200mb between predicted by CFSv2 and observed, and with ACE

4.1.1 Relationship SST between predicted and observed, and with ACE

CFSv2's SST predicting skill is quite high in the Southeastern Japan and in the central WNP warm pool (NTDB defined area) with a correlation coefficient of about 0,4-0,6 at the time of CFSv2 prediction in March and about 0,7-0,8 in June. In general, SST predicting skills are higher when CFSv2 run close to the storm season in the VES. The negative correlation between ACE in the VES with the SST of CFSv2 predicted in all three regions ISST, SSST and JSST, but JSST shows a higher correlation. At the same time, the correlation is positive in the central WNP warm pool.

4.1.2 Relationship U200mb between predicted and observed, and with ACE

At the time close to the storm season in the VES, zonal wind at 200mb level of CFSv2 in the East Asia is more skilled. The value of JSST is predicted by CFSv2 to be lower than that observed by about 1-2^{0}C, while U200 is generally higher from 2 to 4m/s. At the time when CFSv2 run, the closer to the storm season, the smaller the error of the NTDB compared with the observation. The correlation of NTDB between observations and 24 individual predictions (members) is lower than the average of the 24 members. This shows that for predicting ACE, the average of 24 members can be more effective than 24 single members as shown by some authors.

4.3. Establishing the ACE forecasting equation in the East Sea

The predicting equations for ACE1 and ACE2 in the VES are built based on both single and multivariable linear regression methods from the 1982-2010 re-forecast data (dependent data) and quality assessment of The equation is based on the Fisher test with α=5%. NTDB is used to build the equation ACE1, ACE2 as JSST, JSSTG and U200 averaging 24 members in June-August and August-December of CFSv2. Equations satisfying Fisher's test with α=5% will be selected to evaluate the error based on independent data for 6 years and using the criteria include AE, MAE, RMSE, MSSS.

4.3.1 Building equation to predict ACE1

Based on NTDB as JSST, JSSTG and U200 from dependent data for the period 1982-2010, the thesis has set up 12 equations with one NTDBs, 12 equations with two NTDB and 4 equations with three NTDBs to predict ACE1 at TĐPT in months 3, 4, 5 and 6. However, total of 28 equations, only 20 satisfying Fisher's test. Specifically, two equations in March, five equations in April, six equations in May and seven equations in June.

4.3.2 Building equation to predict ACE2

Based on NTDB as JSST, JSSTG and U200 from dependent data for the period 1982-2010, the study has established 6 equations with one NTDB, 6 equations with two NTDBs and 2 equations with three NTDBs to predict ACE1 at TĐPT in May and June. However, out of the total of 14 equations, only 6 equations satisfying the Fisher's test.

4.4 Prediction error of ACE in the Vietnam East Sea

4.4.1 Prediction error of ACE1

The results show that the trend of most of the ACE1 prediction equations is quite similar, high (low) fluctuations relatively in phase with the observation and the errors of the equations are not much different.

4.4.2 Prediction error of ACE2

The results show that the trend of most of the ACE2 prediction equations is also quite similar, high (low) fluctuations relatively in phase with the observation and the errors of the equations are not much different.

4.5 The applicability in operation of ACE prediction in the VES

In order to evaluate the applicability the equations, the RMSE characteristics (section 4.4) and the correct prediction rate of ACE in the VES were used to compare with ACE in the Atlantic Ocean and WNP of TSR, CSU, NOAA. (1) The results show that the RMSE error of ACE prediction in the WNP region is about 30-35% (% of the mean value), about 60-65% in the Atlantic basin. The RMSE error in six independent years of the ACE1 in the AES is about 28-33% and ACE2 is about 35-38%. (2) The correct prediction rates of ACE in the Atlantic basin is about 61-80% and WNP is about 61-82%. Correct prediction rates from 67-83% for ACE1 and 50-83% for ACE2. Thus, there is little difference between RMSE error and correct prediction rates of ACE1 and ACE2 in the VES compared to TSR, CSU, and NOAA. At the same time, the fluctuations of ACE1 and ACE2 is quite similar between predicted and observed. This shows that the predictive equations of ACE1 and ACE2 can be applied in operation.

4.6 Summary of chapter 4

The equations that satisfying Fisher's test are evaluated for errors based on independent data for the period 2013-2018. The evaluation results show that the trend of most of the predicting equations of ACE1 and ACE2 is quite similar, the fluctuations are relatively in phase with the observation and the errors of the equations are not much different. In general, equations can be used to forecast ACE1, ACE2 in the VES at lead time 1-2 months

CONCLUSION AND RECOMMENDATION

1. Conclusion

1) Storm energy assessment

- The time of concentration of storm energy in the Vietnam East Sea is similar to that of the Northwest Pacific basin in July to November, but the peak concentration time is about 1 month later.

- The inter-annual average ACE is about 76.9 x $10^3m^2s^{-2}$, high year is about 140-160 x $10^3m^2s^{-2}$, low year is about 15-20 x $10^3m^2s^{-2}$, standard deviation and coefficient of variation is 32 x $10^3m^2s^{-2}$ and 42%. Higher ACE is about 0.02 to 0.07 x $10^3m^2s^{-2}$ from the North of 16^oN to high latitude, but lower ACE is about 0.01 x 10^3 m^2s^{-2} from 16^0N to low latitude.

- The linear trend of ACE generally decreased in the period from 1982-2018 and increased in the two decades from 1999-2018 but did not reach the 95% statistical confidence according to Student's test.

- The variation of storms in the Vietnam East Sea in the period 1982-2018 have a correlation with SST in the Indian Ocean, in the Southwestern Pacific and in the Southeastern Japan Sea, of which the SST in the Southeastern Japan Sea is strong negative correlation. Specifically, when the SST in the Southeastern Japan Sea is higher, ACE in the Vietnam East Sea is lower and vice versa.

- The results of the principal component analysis show that there exists a close statistical relationship between ACE with PC2 that reflect the intensity of APSJ; A higher APSJ intensity corresponding to a lower JSST will enhance large-scale vertical motion and low level relative vorticity in the Vietnam East Sea and the Eastern Philippine Sea, which favors storm formation and storm entering the Vietnam Sea East, leads to increase ACE.

2) JSSTG, JSST and U200mb applications to predict ACE in the East Sea

- The results of the survey on the correlation between the SST in the Southeastern Japan Sea and the 200 mb zonal wind in the subtropical-East Asia (related to APSJ) based on the CFSv2 re-forecast data show that the applicability for building ACE predictive test equations.

The study has built 26 predictive equations for ACE1 and ACE2 in the Vietnam East Sea satisfying Fisher's test. Specifically, for the ACE1 prediction, there are two equations at TĐPT in March, five equations in April, six equations in May and seven equations in June. For ACE2 prediction, three are three the equations at TĐPT in June and three equations in July. On the basis of comparing the error of predicting ACE1 and ACE2 from independent data with actual operative prediction shown that it can be used 26 equations to prediction with lead time 1-2 months.

3) Ability to use ACE

It is possible to base on information about SST in the Southeastern Japan Sea and APSJ to identify storm trends in the coming storm season. Specifically, the ACE represents “overall activity” for the storm season and often indicates a storm season with many high intense storms, or long duration. Thus, the inter-annual ACE prediction reflect the general trend of potential activity of storm season and it is additional information on number of storms and NCB in predicting storm season trends.

2. Proposal

Researching ACE in Vietnam is a completely new issue with scientific and practical significance. Therefore, this issue needs to be invested in more comprehensive and extensive research in order to improve understanding of storm energy and its application in operative prediction of storm season.

LIST OF SCIENTIFIC ARTICLES OF THE AUTHOR RELATED TO THE THESIS

1) Duong Hoang Trinh, Hoang Duc Cuong, Duong Van Kham, Kieu Chanh (2020), "Remote Control of Sea Surface Temperature on the Variability of Tropical Cyclone Activity Affecting Vietnam’s Coastline”, *Journal of Applied Meteorology and Climatology (JAMC), American Meteorology Society (AMS)*. Volume 60: Issue 3. Page(s): 323–339.

2) Trinh Hoang Duong, Hoang Duc Cuong, Duong Van Kham, Kieu Quoc Chanh (2020), "the possibility of dynamical-statistical prediction for seasonal accumulated cyclone energy in the Vietnam East Sea based on cfsv2". *Vietnam Journal of Hydro Meteorology*, No. 714, pp. 50-61.

3) Trinh Hoang Duong, Hoang Duc Cuong, Duong Van Kham (2018), "Method of assessing storm energy based on energy indicators", *Journal of Climate Change Science, Viet Nam, Institute of Meteorology Hydrology and Climate Change*, No. 6, pp. 9-16 .

4) Trinh Hoang Duong, Hoang Duc Cuong, Duong Van Kham (2020), "Characteristics of storm in the Vietnam East Sea based on storm energy index ", *XXII National Scientific Conference*, *Institute of Meteorology Hydrology and Climate Change.*

5) Trinh Hoang Duong, Hoang Duc Cuong, Duong Van Kham, (2015), “Method of assessing storm based on kinetic energy index”, ", XVIII National Scientific Conference, *Institute of Meteorology Hydrology and Climate Change,* Volume 1, ISBN: 978-604-904-467-7, pp. 86-92