Thunderstorm forecast technique for Noi Bai Airport

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Abstract. This study briefly summarizes the thunderstorm activities in Vietnam. To predict thunderstorms in the Noi Bai Airport region, the thunderstorm indices are calculated for 64 grid points nearby Noi Bai region from the predicted meteorological fields with RAMS (Regional Atmospheric Modeling System) model. The forecast procedure for thunderstorm is built for this region with four prediction factors, such as CAPEmax, Kimax, SI min, Vtmax in the forecast threshold of 0.6. As a result, the occurrence of thunderstorms reaches 80% for the duration of 36 hours. The procedures may be used in the operational prediction.

Keywords: Thunderstorm forecast; Thunderstorm index; RAMS model.

1. Thunderstorms and their activity in Noi Bai area

Thunderstorm is a weather phenomenon concerning to convective clouds which creates heavy rain, strong wind, possibly accompanied by thunder and lightning. Thunderstorm is one of severe weather phenomena, having a great influence on many socio-economic fields, such as aviation, navigation, tourism, construction, electricity, telecommunications,... The occurrence of a thunderstorm usually leads to the occurrence of wind shear, heavy rain, and possibly is accompanied by hail, atmospheric electric discharges, sharp pressure variation,... These meteorological phenomena cause a lot of difficulties for aircrafts in taking off and landing, delaying and even causing damages for traffic means in air and on sea, for manufacturing and human activities. Through the actual operation of Noi Bai Airport it indicates a high number of flights delayed by thunderstorms. In fact, a large amount of aircraft accidents occurred at airports and lanes throughout the world are directly related to thunderstorm. Thus, thunderstorm research and prediction is a vital task at present.

Vietnam is located at Asian thunderstorm center - one of the three most active thunderstorm centers in the world. Thunderstorm occurs in round year within the country, but mostly in rainy season. Thunderstorms in the south of the country is greater than in the north and centre, reducing southward from Thanh Hoa, Nghe An to Quang Binh, Quang Tri, Thua Thien Hue provinces. And the occurrence of thunderstorm in the south of the central part is less significant than that is in the north, reducing from Da

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Nang, Quang Nam to Phu Yen, Khanh Hoa provinces. Particularly, thunderstorms in Ninh Thuan - Binh Thuan which is a well known center of low rainfall is not less than in Phu Yen, Khanh Hoa. In general, Vietnam has a long thunderstorm season lasting from April to September. In mountainous areas of the west of the northern part of the country, thunderstorm season starts in February and ends in October. However, in this region thunderstorm generally isn't the main reason causing heavy rain. Thunderstorm season in the plain areas of the northern part and the north of the central part lasts 7 months (from March to October), and haves about 70-110 thunderstorm days (with the total thunderstorms of about 150-300). The largest numbers of thunderstorm days (about 20 days/month) are observed in June, July, and August. Thunderstorm season in the centre of the central part starts late in April with the total amount of 40-60 days, its greatest number is in May (10-15 days/month). Most of thunderstorms in this region are topographic and thermal ones. The Tay Nguyen region experiences its thunderstorm season from May to October. The central part is the place where thunderstorm frequency is highest, thunderstorm is likely to occur in whole year with the total amount of 120-140 days. The months that have the highest (20-24 days/month) and lowest (1-2 days/month) number of thunderstorms are May and January (or February) respectively [4].

The average number of thunderstorm days in the country is 80 days/year and the average number of thunderstorm hours is 250 hours/year. The popular numbers of thunderstorm days in various region of Vietnam are 20-80 days/year. At some regions, this number excesses 80 days/year, for example Bac Quang (Ha Giang Province): 86.5 days, Hoi Xuan (Thanh Hoa Province): 94.2 days, Phuoc Long: 98.8 days, Tay Ninh: 102.7 days, Moc Hoa (Long An Province): 91.8 days. Most of the regions having an average number of thunderstorm days less than 20 are islands in the central part, such as Con Co: 14.8 days, Hoang Sa: 4.4 days, Truong Sa: 17.4 days, and other places in the south of the central part and Tay Nguyen region, such as Ba To (Quang Ngai Province): 14.4 days, Nha Trang (Khanh Hoa Province): 14.9 days, Cam Ranh (Khanh Hoa Province): 13.8 days, An Khe (Gia Lai Province): 14.9 days [4].

Thunderstorms can occur all year round within the country. Higher frequencies are observed in the summer, frequently in late afternoon or early evening. These kinds of thunderstorm are called thermal ones. Particularly, at mountainous and lake or river areas in hot and wet months, thunderstorms can show their unstable performance, usually accompanied by strong wind gust, possible leading to human death.

Thunderstorm statistical data collected at 82 synoptic surface weather stations located in the whole country in 2003 year were used to calculate the daily thunderstorm probability (Fig. 1).

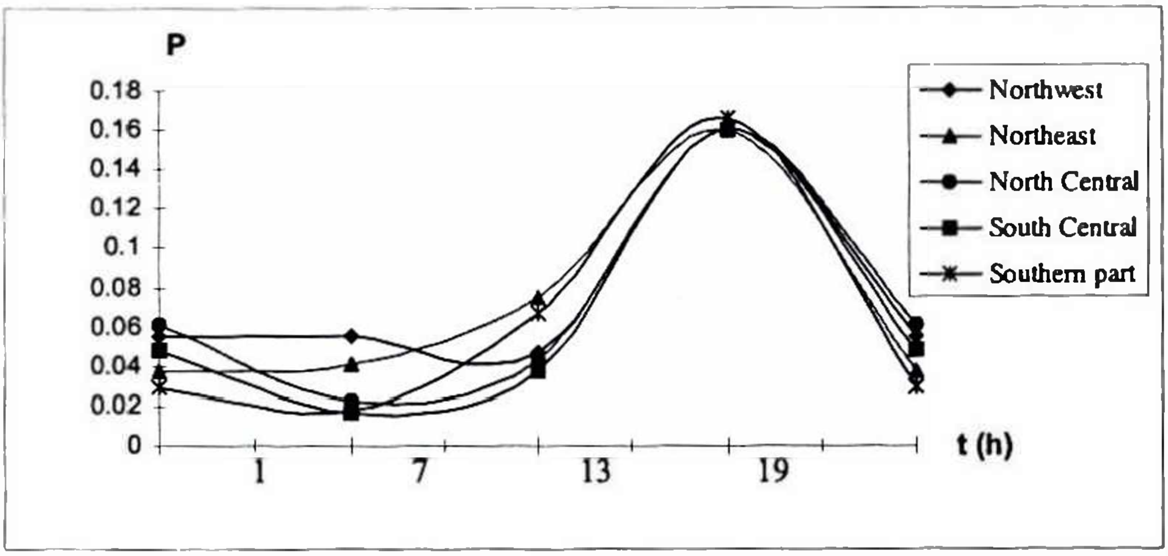

Fig. 1. Daily thunderstorm probability in different regions.

Fig. 1 indicates that in the period from 1pm to 7pm, the highest thunderstorm probabilities were observed in most of regions, their values are much higher than that in other time periods. The lowest probabilities were observed at around 7am, particularly in the mountainous area in the west of the northern part it was from 7am to 1pm. Therefore, we can conclude that in Vietnam thunderstorms mostly occur in the afternoon and in the evening when the thermal supports are most sufficient.

As in other plain regions in the northern part, thunderstorm season in Noi Bai Airport lasts from April to September, having highest frequencies in May, June, July, and August. Based on their formation and progress, thunderstorms in Noi Bai are divided into two kinds: thunderstorms in an air mass (thermal thunderstorms) and thunderstorm at adjacent areas. The former is often observed in the time period from 5pm to 8pm, and latter occurs mostly at night or in the early morning.

2. Studies on thunderstorm in the world

Thunderstorm is a small scale weather phenomenon (10km in scale), thus, predicting whether thunderstorm occurs or not at a certain place is very difficult. There are some thunderstorm forecast methods available in the world such as using the instability index, statistical method, and fluid dynamic method. The most widely used thunderstorm indices are Boyden, CAPE, LI, K, etc. To make a judgment on whether an index has significant predictive potential or not for a certain region, it is necessary to look into the statistical relation between the index and the thunderstorm occurrence at that region. Scientists in different countries have investigated different thunderstorm indices for their particular regions, such as studies of Schultz (1989) for Colorado, Jacovide and Yonetani (1990) for Cyprus, Huntrieser (1997) for Switzerland, Yonetani for Kanto (Japan), Van Delden (2001) for the Netherlands [1, 2].

In recent years, the value of different thunderstorm indices can be easily computed using the numerical model outputs and rawinsonde data. Furthermore, several statistical forecast models have been developed based on meteorological variables and instability indices represent the atmospheric state before convection.

In 2004, Maurice J. Schmeits at Royal Netherlands Meteorology Institute (KNMI) used the combination of outputs from two numerical models of HIRLAM (mesoscale numerical model) and ECMWF to calculate 15 thunderstorm indices for separate sub-regions of about 90x80km each. Five selected predictors are CAPE, Jefferson, Boyden, the level of neutral buoyancy, Rackliff were included in the forecast equation [5].

The instruction on how to compute and use atmospheric instability indices for forecasting thunderstorm is available on the website http://www.downunderchase.com/storminfo. The indices used for thunderstorm forecast in Australia are also available on this website.

In Vietnam, due to the limitation on modern technology, only a few researches on cloud structure of thunderstorm have been implemented. Tran Duy Binh had his research on convective cloud in Ho Chi Minh City, and Truong Quan Thuy has conducted discrimination equation for forecasting thunderstorm at Noi Bai Airport.

Nguyen Vu Thi has predicted thermal thunderstorm occurrence in May and June with leadtime of 6-12 h for Hanoi area using successive diagrams in correspondence with couples of meteorological variable at 7 am (T,Td), (dd600, ΔT1000-850), (dd700,ff700) for May and (T,Td), (dd600(t), dd600(t-1)), (dd850,ff700). Space on each diagram is divided into two zones: thunderstorm and non-thunderstorm.

Dinh Van Loan has built multi-element scatter diagram to predict thunderstorm for Noi Bai area in May, June, July which is the period when the west warm depression occupies the northern part of Vietnam. The horizontal line represents the value of ΔT1000-700, the vertical line represents the value of Σ(T-Td)/3. The space on diagram was divided into three zones corresponding to different thunderstorm probabilities. The thunderstorm forecast was based on these zones on the diagram.

In 2002, Nguyen Viet Lanh computed 7 atmospheric instability indices of SI, LI, CI, SWI, KI, TT, FMI derived from rawinsonde data of Hanoi station at 00Z within 15 years, using stepwise regression method to select potential predictors and conduct the forecast equation [3].

3. Conducting thunderstorm forecast equation for Noi Bai subregion

Thunderstorm indices have been computed based on meteorological fields for projection out to 48 hours using the RAMS model on the second grid of the computed region including two grids. The first grid has a horizontal resolution of 28 km for the forecast region of 140x140 grid points with the actual size of 3892x3892 km^2. This computed area covers the whole area of Vietnam and partly China. The second grid has a horizontal resolution of 9 km for the forecast region including 65x65 grid points with the region size of 576x576km^2, Noi Bai is located in the center of the forecast region.

3.1. Predictor

Total day time (24 hours) is divided into four intervals (6 hours for each) with the start time of 00Z, 06Z, 12Z, and 18Z. In the time period of 6h ($t_i <= t < t_{i+1}$, where i is the start time mentioned above). If thunderstorm is detected by the METAR or SPECI then it is expected to occur in Noi Bai. In this case, thunderstorm predictor attains the value of 1. Conversely, thunderstorm predictor has the value of 0 if no thunderstorm is detected in the 6 hours time period. Predictor data contain 504 observing times within 144 days of three months (May, June, and July) in three years (2005, 2006, and 2007).

3.2. Predictand

Computed region is the grid surrounding Noi Bai station with the region of size 63x63km including 64 grid points. From the meteorological output fields of RAMS model, the value of 20 thunderstorm indices has been computed using RAOBS 5.6 software. After that, the maximum, minimum, and average values of each index at each grid point are computed. These values are considered as potential predictors (3x20=60 potential predictors in total). The value of these 60 indices are derived at lead time of 06, 12, 18, 24, 30, 36, 42 with 72 forecasts within 3 months (May, June, and July) in three years (2005, 2006, and 2007), resulting in a dataset of 72x7=504 forecasts. These predictors at a certain time of ti are used for predicting thunderstorm event in the 6-h time period (ti<=t<ti+1, where i is the start time mentioned above).

The computing process of conducting forecast equation is shown in Fig. 2.

3.3. Predictor selection

Based on the set of data above, the predictand of xi is divided into two weather phases: $\phi1$ (non-thunderstorm) and $\phi2$ (thunderstorm). In each cluster, the maximum and minimum values are picked out. The representatives of these values in two clusters are xmax1, xmax2 and xmin1, xmin2. The overlap area of these two clusters is determined as:

$$\delta=\min(xmax1,xmax2) - \max(xmin1,xmin1)$$

Determination area of x with respect to the data is:

$$\Delta=\max(xmax1, xmax2) - \min(xmin1,xmin2) - S$$

where $S = \delta$ if $\delta<0$ and $S = 0$ if $\delta>0$

The norm of predictor selection is then:

$$R=\frac{\delta}{\Delta} \quad (1)$$

The data output of the model consists of 504 forecasts. Data from the 363 forecasts are used as a dependent set so as to conduct the thunderstorm forecast equation, and the rest of 141 forecasts are used as a independent set to verify the accuracy of the forecast method.

Initially, 60 indices with the length of 363 forecasts are accessed basing on R norm to gain the predictors having most predictive potential. The result of computing these norms following formula (1) is presented in tables 1, 2 , and 3.

Table 1. R norms with respect to maximum thunderstorm indices at 64 grid points

Index	BOYDEN	BRN	BRN sh	CAP	CAPE	CT	EHI	Jeff	KI	KO
R	0.98549	0.63374	0.99307	0.75889	0.19058	0.84175	0.82333	0.95247	0.24004	0.787972
Index	LI	S	SI	Hel	Sweat	Thomp	TT	VGP	VT	Windex
R	0.72493	0.51753	0.68484	0.8573	0.70141	0.78632	0.41772	0.57143	0.21694	0.671486

Table 2. R norms with respect to average thunderstorm indices at 64 grid points

Index	BOYDEN	BRN	BRN sh	CAP	CAPE	CT	EHI	Jeff	KI	KO
R	0.80643	0.89741	0.74866	0.96265	0.66699	0.91086	0.83507	0.76502	0.60684	0.778107
Index	LI	S	SI	Hel	Sweat	Thomp	TT	VGP	VT	Windex
R	0.72995	0.51753	0.79955	0.87559	0.85774	0.88537	0.89998	0.68021	0.99737	0.759424

Table 3. R norms with respect to minimum thunderstorm indices at 64 grid points

Index	BOYDEN	BRN	BRN sh	CAP	CAPE	CT	EHI	Jeff	KI	KO
R	0.89843	0.84258	0.99536	0.86009	0.84875	0.84175	0.72563	0.95247	0.72556	0.434846
Index	LI	S	SI	Hel	Sweat	Thomp	TT	VGP	VT	Windex
R	0.72493	0.51753	0.2973	0.8573	0.6986	0.78632	0.88096	0.57143	0.57764	0.671486

The closer the R to 1, the less the discrimination ability of the predictor is, and the closer the R to 0, the larger the common field of two weather phases is. Thus, from the result calculated in three tables above (3.4, 3.5, 3.6), six predictors having the R<0,5 are CAPEmax, VTmax, KImax, SImix, TTmax, and KOmin. Among them, CAPEmax appears to have most predictive potential (0.19058) so it is our first priority. The other five indices are then selected based on correlation coefficients between them. The computed correlation matrix is shown in Table 4.

Table 4. Correlation coefficients between 6 predictors

	CAPEmax	KImax	KOmin	SImin	VTmax	TTmax
CAPEmax	1	0.336	-0.475	-0.386	0.384	0.590
KImax	0.336	1	-0.785	-0.289	0.356	-0.960
KOmin	-0.475	-0.785	1	0.631	-0.607	-0.466
SImin	-0.386	-0.289	0.631	1	0.228	-0.462
VTmax	0.384	0.356	-0.607	0.228	1	0.597
TTmax	0.590	-0.960	-0.466	-0.462	0.597	1

Table 4 indicates that KOmin and TTmax has very good relations with other predictors. The correlation coefficient between KOmin and CAPEmax is -0.475, TTmax and CAPEmax is 0.59, TTmax and KImax is -0.96,... Thus, these two predictors were removed from the forecast equation. Initially, 4 predictors were decided to be included in the forecast equation are: CAPEmax, KImax, VTmax và SImin.

Discrimination equation used for thunderstorm forecasting at Noi Bai Airport area is:

$$I=-0.001.CAPEmax-0.071.KImax+0.289.SImin.226.VTmax-7.253 \qquad (2)$$

The result of assessing the forecast of two phases using these indices is:

Table 5. Forecast assessment based on the dependent set of data

Index	Using discrimination function	Forecast process
H	0.705	0.810
POD	0.698	0.699
FAR	0.197	0.197
POFD	0.284	0.115
CSI	0.597	0.596
TSS	0.415	0.583
Heidke	0.398	0.596

Table 6. Forecast assessment based on the independent set of data

Index	Using discrimination function	Forecast process
H	0.710	0.773
POD	0.767	0.767
FAR	0.521	0.521
POFD	0.325	0.225
CSI	0.418	0.418
TSS	0.442	0.541
Heidke	0.374	0.444

Forecast equation was verified using the independent set of 141 forecasts, 34 of which had CAPEmax<700J/kg, leading to the forecast of non-thunderstorm. The other 107 cases were included in the discrimination equation (2).

The forecast results displayed in tables 5 and 6 indicate that Hiedke index reaches 0.596 and POD reaches 0.699 when the dependent set is used. When the independent set is used, the corresponding numbers are 0.444 and 0.767.

Using multi-variable linear regression method we got the equation as:

I=0.0003.CAPEmax-0.0133.KImax-0.0538.SImin-0.0421.VTmax+1.946 (3)

To determine the forecast threshold included in regression equation (3), we have attributed φ to different values. φ=0.3, φ=0.4, φ=0.5, φ=0.6, φ=0.7, φ=0.8 have been respectively included in the equation, and then we computed the indices of verification result under the condition of I> φ (thunderstorm alarm is issued).

The results of verification of indices derived from the combination of filtering method and regression equation are presented in Table 7.

Table 7. Verification of results derived from the combination of filtering method and regression equation with respect to φ

Index	0.3	0.4	0.5	0.6	0.7	0.8
H	0.780	0.824	0.813	0.810	0.769	0.711
POD	0.973	0.925	0.801	0.699	0.514	0.315
FAR	0.349	0.282	0.250	0.197	0.148	0.098
POFD	0.350	0.244	0.180	0.115	0.060	0.023
CSI	0.640	0.678	0.632	0.596	0.472	0.305
TSS	0.622	0.680	0.622	0.583	0.454	0.292
Heidke	0.576	0.650	0.615	0.596	0.485	0.327

To verify the forecast results, the independent set has been used in conjunction with filtering method and regression equation. The indices of verifying forecast results are shown in Table 8.

Table 8. Verification forecast results derived from the combination of filter method and regression equation on the independent set

Index	0.3	0.4	0.5	0.6	0.7	0.8
H	0.489	0.546	0.660	0.794	0.823	0.801
POD	1.000	0.833	0.833	0.833	0.633	0.367
FAR	0.706	0.702	0.632	0.490	0.424	0.450
POFD	0.649	0.532	0.387	0.216	0.126	0.081
CSI	0.294	0.281	0.342	0.463	0.432	0.282
TSS	0.351	0.302	0.446	0.617	0.507	0.286
Heidke	0.187	0.182	0.305	0.501	0.489	0.325

The forecast threshold was chosen under the condition that the indices of H, POD, CIS, TSS, Heidke are maximum and the indices of FAR, POFD are minimum. Table 8 demonstrates that the forecast threshold of 0.6 (φ = 0.6) leads to the best results. Therefore, φ = 0.6 was finally chosen.

The use of the method of Phan Lop and of linear regression on the dependent set including 363 cases leads to the similar thunderstorm forecast results at Noi Bai. However, on the independent set, the performance of the combination of filter method CAPEmax < 700 J/kg and regression equation having the forecast threshold of 0.6 (φ = 0.6) is better. Thus, we chose the latter procedure to conduct the forecast equation for Noi Bai region. This forecast process is shown in Fig. 3.

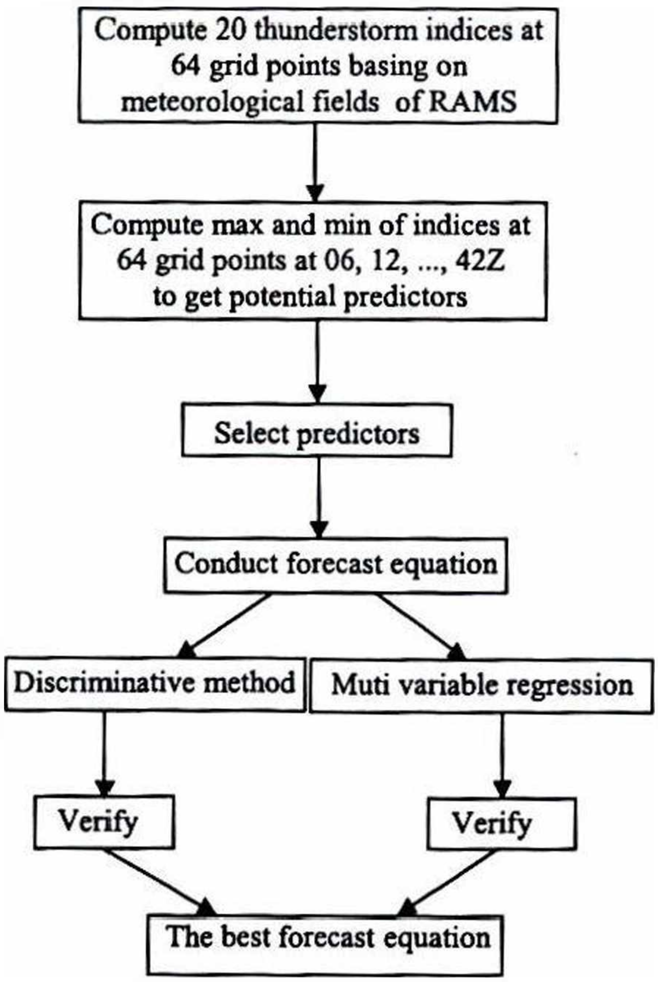

Fig. 2. The workflow of computing process.

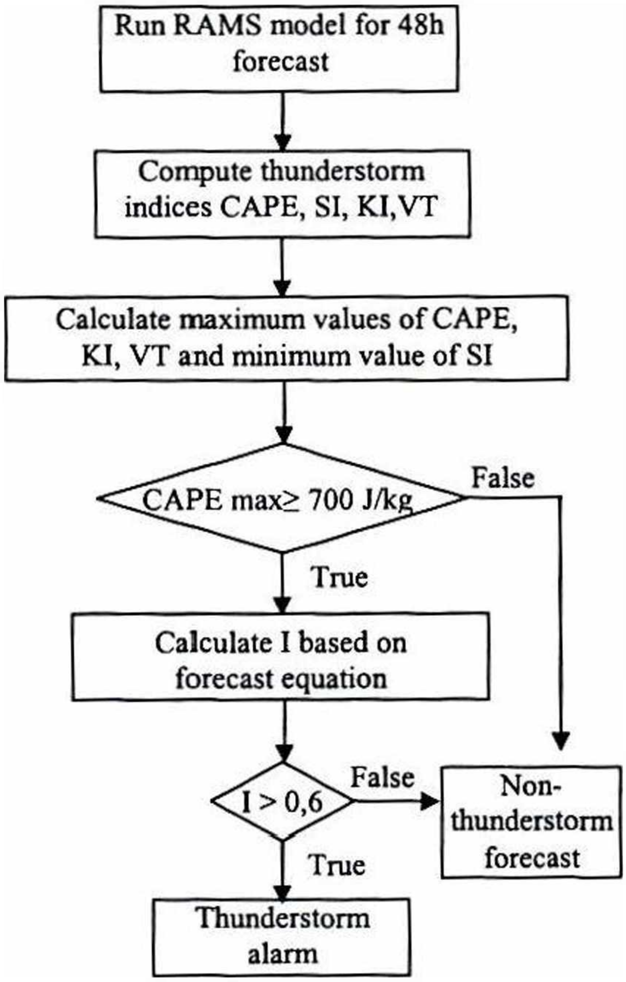

Fig. 3. The workflow of forecast process.

4. Conclusions

1. RAMS model is a mesoscale numerical weather prediction model that has been widely used for many different purposes. The experimental results demonstrated that the use of RAMS model can lead to the ability of computing thunderstorm indices for 48 subsequent hours.

2. Based on the study of 20 thunderstorm indices, we have found out four suitable thunderstorm indices for forecasting thunderstorm at Noi Bai area.

3. We have conducted the forecast methods using the combination between filtering method, discrimination method, and multi-variable linear regression method. Based on the verification of results, the thunderstorm forecast process for Noi Bai area has been presented. It uses the RAMS model output for the lead time of 36 hours to compute thunderstorm indices as predictors and combining filtering method and 4-variable linear regression equation CAPEmax, SImax, KImax, VTmax and the forecast threshold of 0.6. This technique is being applied for thunderstorm forecast of Noi Bai area.

Acknowledgements

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