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# PREDICTION OF TROPICAL DISTURBANCE DEVELOPMENT OVER THE SOUTH CHINA SEA USING SSM/I DATA

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**Abstract:** This paper proposes a method for predicting the development of tropical disturbance over the South China Sea (SCS) based on the total latent heat release (TLHR) derived from the Special Sensor Microwave/Imager (SSM/I) satellite observations. A threshold value of daily mean TLHR (3×1014 W) for distinguishing the non-developing and developing tropical disturbances is obtained based on the analysis for 25 developing and 43 non-developing tropical disturbances over the SCS during 2000 to 2005. If the mean TLHR within 500 km of a disturbance on the latest day and its daily mean TLHR during previous life are both greater than 3×1014 W, the disturbance will be a developing one in the future. Otherwise, it is a non-developing one. A real-time testing prediction of tropical cyclogenesis over the SCS was conducted for the years 2007 and 2008 using this threshold value of TLHR. We find that the method is successful in detecting the development of 80% of all tropical disturbances over the SCS in 2007 and 2008.

**Key words:** South China Sea; TLHR; SSM/I; cyclogenesis

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## 1 INTRODUCTION

Tropical cyclone (TC) is one of the most destructive mesoscale weather systems. The early precursor of TC is tropical disturbance[1, 2]. A tropical disturbance is a discrete tropical weather system of apparently organized convection, generally 200 to 600 km in diameter, that originates in the tropics or subtropics, having a non-frontal migratory character and maintains its identity for 24 hours or more[3]. However, as real-time observations[4] show, not all tropical disturbances could develop to tropical depressions, and most of them would become weaker gradually and disappear in the end. The average life time of a tropical disturbance is about two or three days.

Previous researches have been done to find out the mechanisms of tropical cyclogenesis associated with the large-scale circulation and climate background[5, 6]. Unfortunately, this background climatology often means little to the cyclone forecaster with day-to-day requirements to make TC-formation predictions. In terms of day-to-day prediction for tropical cyclone formation, Dvorak once used cloud features to estimate the cyclone's intensity and its further changes[7]. McBride and Zehr[8] defined a parameter of Daily Genesis Potential (DGP) for the potential of a system to develop into a hurricane or typhoon. Katsaros et al.[9] assumed that the presence of closed circulation in the surface winds before depressions provide valuable guidance for cyclone forecasting. Sharp et al.[10] found that the appearance of positive vorticity that exceeds a certain threshold magnitude and horizontal extent within the swath of vector wind observations is useful for early detection of TC genesis. Venkatesh and Mathew[11] proposed that the merger of mesoscale midlevel vortices could be a common precursor event, and used a vortex merger index to detect cyclogenesis at early stage. However, although all of them proposed some methods or phenomena to detect and forecast TC genesis, they were not discussing the actual criteria. An actual criterion for day-to-day requirements is still needed to make formation predictions.

The South China Sea (SCS), the largest

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semi-enclosed marginal sea extending from the equator to 23°N and from 99° to 120°E in the Northwest Pacific, is an area with frequent TC genesis. Usually, it takes 2-10 days for the named storms to make landfall in SCS[12]. So finding a threshold for developing disturbances in SCS is important to government and society.

The energy of tropical disturbances comes from interaction between cumulus-scale convection and synoptic-scale dynamic field. The large-scale flow provides moisture convergence necessary for the convection[13, 14], and the heating due to condensation maintains large disturbances[15]. As early as in 1981, Rogers and Adler[16] found that the increasing latent heat release (LHR) is the first indication of TC intensification 1-2 days prior to the TC reaching storm stage. Wang[17] compared 30 non-developing and 13 developing disturbances over the SCS in 2000 and 2001 using satellite and reanalysis data sets in order to understand why some disturbances developed into cyclones, while others did not[17]. One index of latent heat release (ILHR)—combining five factors (including sea surface temperature, difference of wind divergence between 850 and 200 hPa, relative humidity at 500 hPa, relative vorticity at 850 hPa and outgoing long wave radiation)—is defined to predict the development of tropical disturbances. When comparing ILHR with the total latent heat release (TLHR), which is influenced by both the dynamic conditions and thermodynamic conditions, Wang[18] found that the correlation coefficient between ILHR and TLHR is 0.780, which is statistically significant with 95% confidence level. Therefore, the latent heat release through condensation and precipitation processes is essential for determining the development and maintenance of tropical disturbances. TLHR may be a good parameter to predict tropical cyclogenesis. Wang et al.[18] analyzed the tropical disturbances over the South China Sea (SCS) in 2000 and 2001, found that the TLHR of most developing disturbances is above $6\times10^{14}$ W, while that of most non-developing ones is below $2\times10^{14}$ W. Therefore, $2\times10^{14}$ W and $6\times10^{14}$ W may be two important values of mean latent heat release within 500 km of the center of tropical disturbance to distinguish the developing and non-developing tropical disturbances. This paper is organized to extend the statistics to 2005, proposes a criterion of prediction based on satellite observations, and tests the criterion for the prediction of the development of tropical disturbances over the SCS in 2007 and 2008.

## 2 DATA

The Special Sensor Microwave/Imager (SSM/I) data products, including ocean wind speed (at 10 m), water vapor, cloud water, and rain rate, are produced as part of the Defense Meteorological Satellite Program (DMSP) since 1987[19]. The DMSP satellite which circles around Earth 14 times a day is a polar-orbiting platform in a nearly Sun-synchronous orbit. Remote sensing systems generate SSM/I data products using a unified, physically based algorithm. The propagation of the microwave radiation through the atmosphere is influenced by the integrated amounts of water vapor and liquid water in the atmospheric column. Therefore, the brightness temperatures carry signals that can then be converted into geophysical parameters using retrieval algorithms[20, 21]. The data used in this study are from three satellites (F13, F14 and F15), which could overlay the entire domain we investigated in this study, with a horizontal resolution of 0.25°×0.25°.

The records of tropical disturbances over the SCS used in this study are from topical disturbance alert messages forwarded, as Tropical Storm and Hurricane WX (WX-TROPL) products, by the University of Illinois at an Urbana-Champaign (UIUC) weather server. The originator of these alert messages includes various national weather services, including the Joint Typhoon Warning Center (JTWC), the Japan Meteorological Agency (JMA), and the Hong Kong Observatory (HKO). Satellites data are used in the products to confirm the position of tropical disturbances and tropical cyclones on a daily basis. In this paper, if a disturbance could develop and upgrade to a tropical depression, it is defined as a ’developing disturbance’. Otherwise, it is defined as a ’non-developing disturbance’. A disturbance day is defined as a day in which a disturbance is observed over the SCS. A disturbance event is referred to the whole lifetime of a disturbance from its formation to its enhancement or dissipation. The disturbances discussed in this study only include those that formed originally within the SCS.

## 3 STATISTICS OF TROPICAL DISTURBANCES

### 3.1 *Total latent heat release*

TLHR is calculated by the rain rate observed from SSM/I according to Eq. (1) given by Adler and Rodgers[15].

$$TLHR = L\rho\int_A Rda \qquad (1)$$

where $\rho$ is the density of rain ($1.0\times10^3$ kg m$^{-3}$), and $L$ is the latent heat of condensation ($2.5\times2.5\times10^6$ J kg$^{-1}$). $A$ is the area of integration (a circle with the radius of 500 km) and $R$ is the rain rate, which is from the measurements of SSM/I data of F13, F14 and F15 on a daily basis. Mean TLHR within 500 km of the center of tropical disturbance for 25 developing ones and 43 non-developing ones over the SCS during

2000 to 2005 is shown in Figure 1.

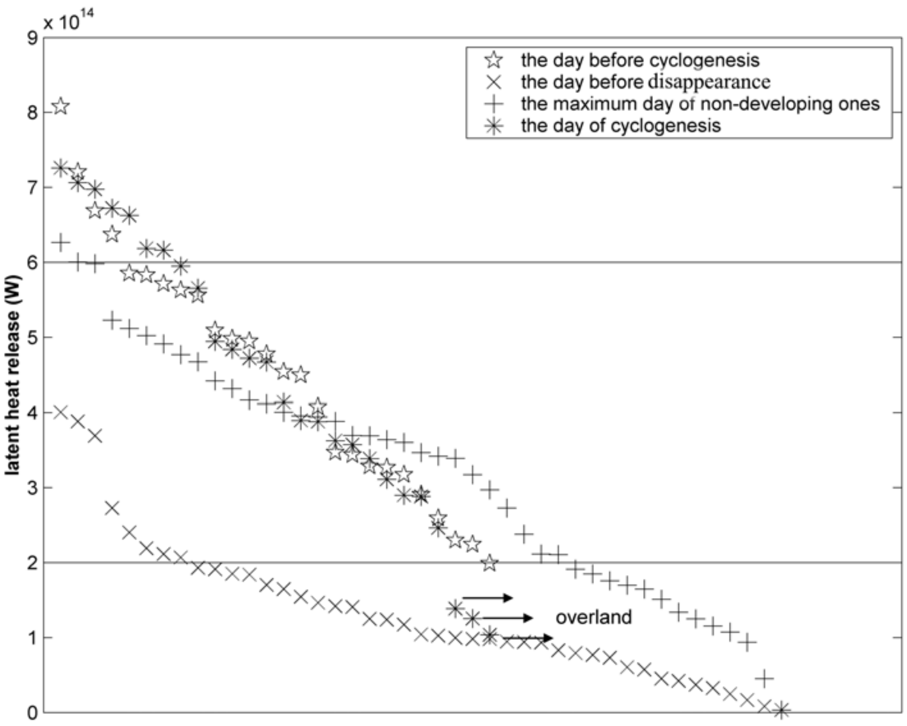


**Figure 1.** The distribution of mean TLHR within 500 km of the center for 25 developing and 43 non-developing tropical disturbances over SCS during 2000 to 2005. The disturbances in the figure are arranged in a descending order of latent heat release. Therefore, the *x*-axis is not labeled.

For developing disturbance, mean TLHR of their generation day (the day when a tropical depression generates) is not always larger than that of the day before cyclogenesis. If we only analyze the mean TLHR on the day before cyclogenesis or their disappearance, $2\times10^{14}$ W and $6\times10^{14}$ W are two clear criterions to differentiate them. The mean TLHR for developing disturbances one day before their cyclogenesis is greater than $2\times10^{14}$ W, while the mean TLHR is lower than $2\times10^{14}$ W for 81.4% of non-developing disturbances one day before their dissipation. There are only 4 developing cases with mean TLHR larger than $6\times10^{14}$ W one day before their genesis. However, the maximum daily mean TLHR exceeds $2\times10^{14}$ W for 69.8% of all non-developing cases. It is difficult to predict whether a tropical disturbance could develop or not using the TLHR threshold value of $2\times10^{14}$ W and $6\times10^{14}$ W.

3.2 *Accumulated latent heat release*

Accumulated latent heat release (ALHR) is defined as the summation of daily TLHR during the lifetime of a tropical disturbance. The ALHR of the tropical disturbance at the day *n* can be calculated according to Eq. (2).

$$(\mathrm{ALHR})_n = \sum_{i=1}^{n} (\mathrm{TLHR})_i \qquad (2)$$

where, $(TLHR)_i$ is TLHR at the day *i*.

Figure 2 presents the variation of mean ALHR within 500 km of the center of tropical disturbance during their whole life over the SCS during 2000 to 2005. The green line and pink line are criterions with the constant daily mean TLHR of $2\times10^{14}$ W and $6\times10^{14}$ W per day separately. The slopes of red lines which represent developing disturbance are nearly greater than that of blue lines which represent non-developing ones in Figure 2. One dark line with the constant daily mean TLHR of $3\times10^{14}$ W is used to separate developing disturbances and non-developing disturbances, which is better than that using the pink or green line. 21 out of 25 developing disturbances and 34 out of 43 non-developing disturbances could be estimated according to this standard. Most tropical disturbances over the SCS may need certain energy every day to maintain their intensity and to develop. The amount of energy determines whether a disturbance could develop into a tropical depression or not.

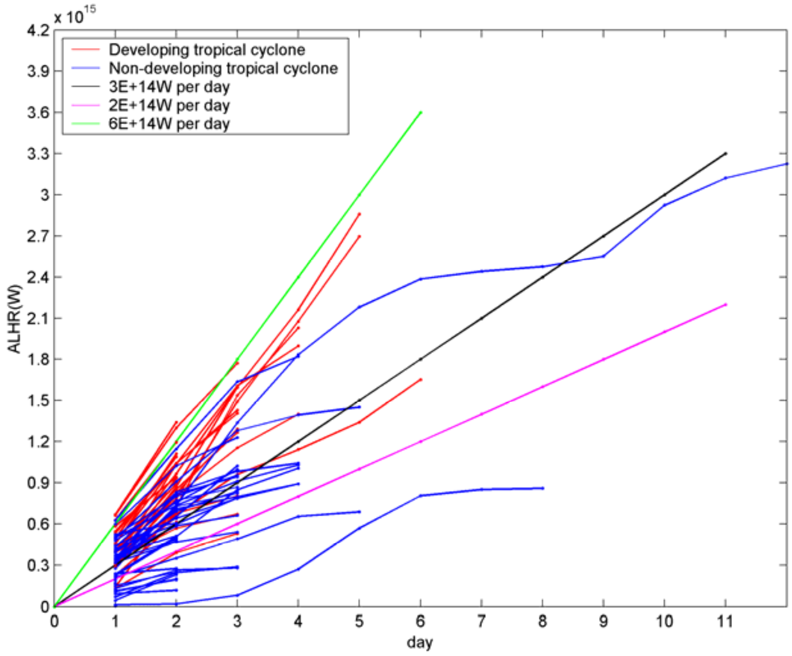


**Figure 2.** The variation of daily mean ALHR within 500 km of the center of disturbances during 2000 to 2005. The red lines are for developing disturbances and the blue lines are for non-developing ones.

As shown in Figure 1, the value of the mean TLHR for nearly all of the developing disturbances is larger than $2\times10^{14}$ W. For a developing disturbance with mean TLHR of $3\times10^{14}$ W, the energy of $2\times10^{14}$ W is assumed to maintain itself and $1\times10^{14}$ W is to heat the upper level of cumulus. The decrease of surface pressure could be estimated by a simple calculation as follows.

### 3.3 *Idealized model*

We assumed an air column with radius of 500 km, in which the air only flows out from the top. In an isometric process, when TLHR is released, the air at the upper level will expand and flow out of this air column and the surface pressure decreases at last. The decrease of surface pressure ($\Delta p$) is determined by air mass loss of the whole column.

$$dQ = C_p m dT \quad (3)$$

$$dH = \frac{RdT}{g}\ln\left(\frac{p_{500hPa}}{p_{200hPa}}\right) \quad (4)$$

$$dP = -\rho g\, dH \quad (5)$$

where d$Q$ is the energy of $1\times10^{14}$ W, $C_p$ is specific heat content at constant pressure ($1005\,\mathrm{J\cdot kg^{-1}\cdot K^{-1}}$), $m$ indicates the mass of air between 200 hPa and 500 hPa, $dT$ is the variation of temperature, $dH$ means the height increase of air column, $R$ is the molar gas constant ($287\,\mathrm{J\cdot kg^{-1}\cdot K^{-1}}$), $g$ is the acceleration of gravity (10 m $s^{-2}$), and $\rho$ is the density of air at the upper level which is equal to 0.33 kg $m^{-3}$ according to American Standard Atmosphere[22]. The equations show that when the air column between 500 hPa and 200 hPa is heated by $1\times10^{14}$ W, the surface pressure could drop by 3.2 hPa, which matches the conditions in TC genesis. The calculations from this simple model prove that $10^{14}$ W is a reasonable magnitude of latent heat release in tropical cyclogenesis.

### 3.4 *Threshold to distinguish developing and non-developing disturbances*

In conclusion, average daily mean TLHR of $3\times10^{14}$ W within 500 km of the center of tropical disturbance during their life is a good threshold to distinguish developing disturbances from non-developing disturbances over the SCS. As shown in Figure 2, for some non-developing disturbances, the mean TLHR on the first day is so large that the average daily mean TLHR in the following days is greater than $3\times10^{14}$ W, even though the mean TLHR may be less than $3\times10^{14}$ W after the first day. To avoid this error, whether daily mean TLHR is more than $3\times10^{14}$ W should be considered. Then the threshold for developing and non-developing disturbances can be concluded into two conditions: one is that its average daily TLHR is greater than $3\times10^{14}$ W, and the other one is that the TLHR of the latest day is greater than $3\times10^{14}$ W. If these two conditions are satisfied, it will be more possible for a disturbance to upgrade in the future. Otherwise, it will tend to dissipate.

According to the two conditions above, all of the tropical disturbances during 2000 to 2005 are examined and the results are compared with the observation, both for disturbance days and disturbance events (Figure 3). If the prediction for a day agrees with the observation for the next day, it is called a "correct day". Otherwise, it is called an "incorrect day". If a disturbance can be predicted according to the criterion one or more days earlier, it is called a "correct event", and otherwise, it is called an "incorrect event". There are 199 disturbance days and 68 disturbance events in SCS from 2000 to 2005. Among the 199 disturbance days, 164 of them are correct days. The accurate rate of disturbance day is 82.4%. Of all the disturbance events, 61 are correct events, and the success rate is 89.7%. As shown in many previous researches, seasonal variation of disturbances is obvious in the SCS[6, 23]. The period from Jul to October is a "peak TC season", in which the average monthly number of events is 8.75, while in the "neap TC season" from January to April, the average monthly number of events is 1.5. The months with the highest success rate are March and April, in which every day and event is correct. October has the lowest success rate of event (66.7%) and day (68%). In most cases a correct day has a positive correlation with correct events.

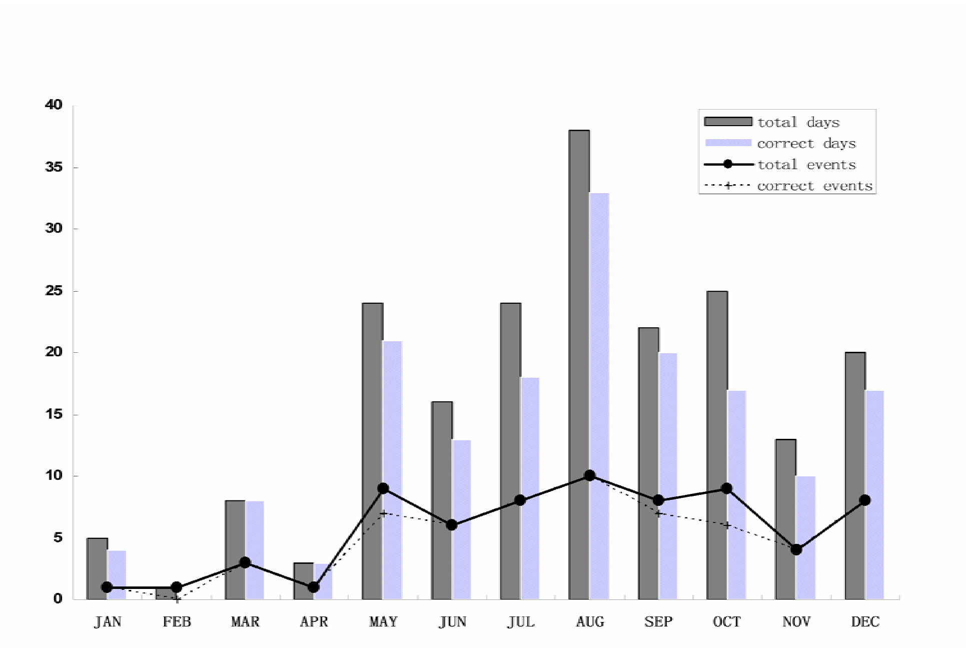


**Figure 3.** The checkout of criterions in every month from 2000 to 2005.

Figure 4 presents the correct and incorrect days of each disturbance in its lifetime. For developing disturbances, the rate of correct day is 89.3%, while it is 68% for non-developing disturbances. 51.4% disturbances can be predicted correctly three days before, and 78.6% disturbances can be predicted correctly two days before, and 92.3% disturbances can be predicted one day before their upgrading or dissipation. Another important phenomenon is that for non-developing disturbances, once the previous average daily TLHR is less than $3\times10^{14}$ W, they will never upgrade to depression any more, even though some of them may last for a long time.

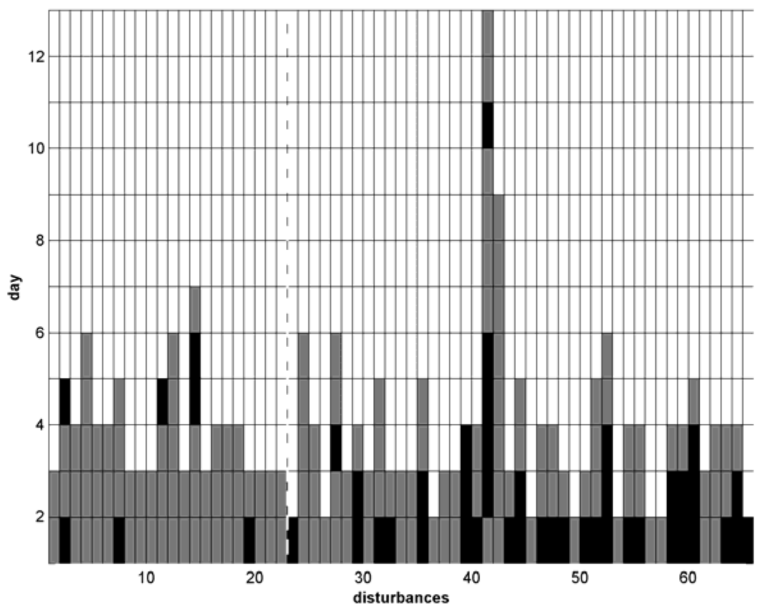


**Figure 4.** Comparison of prediction and observation in each disturbance day. Developing disturbances are on the left of the dotted line while non-developing disturbances are on the other side. The grey bar stands for correct day, and the black one stands for incorrect day.

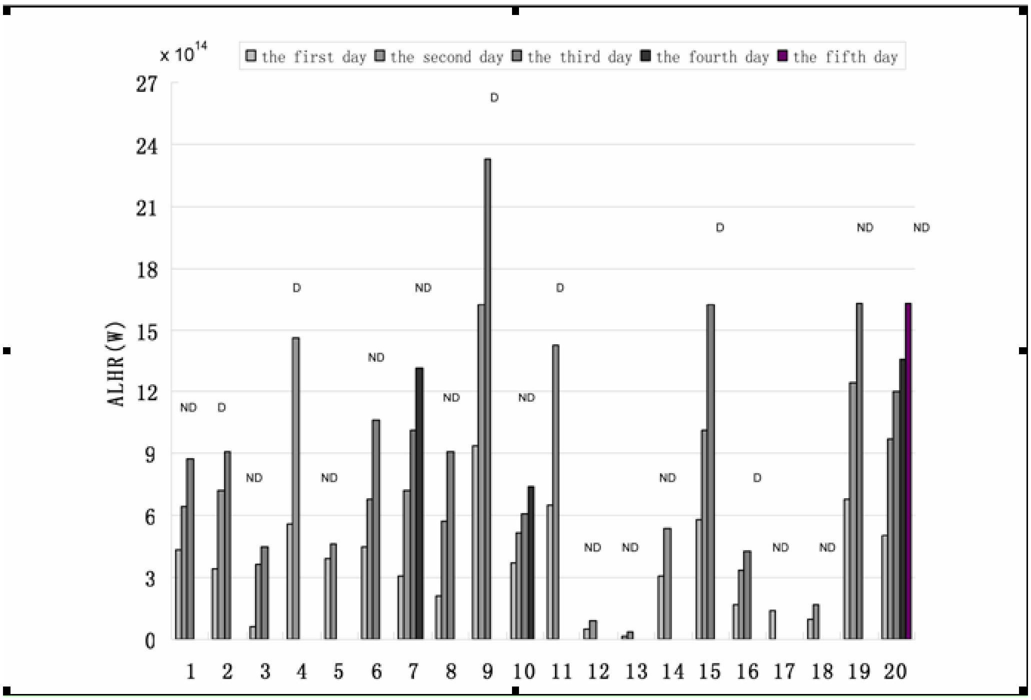


**Figure 5.** Mean ALHR within 500 km of the center of 20 disturbances over the SCS from 2007 to 2008. The disturbances marked with "D" are developing while the disturbances marked with "ND" are non-developing.

### 3.5 *Real-time prediction for 2007 and 2008*

Based on the criterion above, a real-time prediction system is set to predict the tropical cyclogenesis in 2007 and 2008 over SCS (Figure 5). There are 20 events (6 of them are developing and 14 are non-developing) and 55 disturbance days from 2007 to 2008. Among the 55 (20) disturbance days (events), 46 (16) are correct days (events). The rate of correct days is 83.6%, and the rate of correct events is 80%. The real-time prediction results prove that it is an effective method to predict the disturbances using TLHR from SSM/I data. It should be noted that the four failed predictions of disturbances all occurred in autumn, which also has lower success rates during 2000 to 2005. It is implied that there should be some other external factors in determining the development of disturbance in autumn.

## 4 CONCLUSIONS

On the basis of disturbance records from WX-TROPL Tropical Storm and Hurricane WX products and satellite data from SSM/I, mean TLHR of developing and non-developing disturbances during 2000 to 2005 over the SCS is analyzed, and an attempt is made in this study to assess and predict whether a disturbance could develop or not on a daily basis by calculating TLHR. Our analysis shows that if the mean TLHR within 500 km of a disturbance on the latest day and its daily mean TLHR during previous are both greater than $3\times10^{14}$ W, the disturbance will be a developing one in the future. Otherwise, it is a non-developing one. Among 199 disturbance days from 2000 to 2005, 164 of them can be predicted correctly one day before, and the success rate is 82.4%. In the 68 disturbance events from 2000 to 2005, 61 disturbances can be predicted one day before their upgrading or dissipation, and the success rate is 89.7%. According to the criterion, a real-time prediction system is established. From the verification in 20 disturbance events and 55 disturbance days over the SCS from 2007 to 2008, the success rate of disturbance events is 80%, and the success rate of disturbance day is 83.6%. The result suggests that TLHR is a useful factor in the prediction of tropical cyclogenesis. For non-developing disturbances, our statistics imply that once the average daily mean TLHR is less than $3\times10^{14}$ W, they would never reach the level of depression.

In addition, some problems are still unresolved. For instance, some disturbances are not well predicted in autumn during statistic and real-time forecasting, which needs to be studied in more details. Furthermore, questions remain on whether this method would be suitable for other tropical cyclogenesis regions.

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