Revision of JMA's Early Stage Dvorak Analysis and Its Use to Analyze Tropical Cyclones in the Early Developing Stage

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Abstract

This report follows Kishimoto et al. (2007). The Japan Meteorological Agency (JMA) conducted verification of the behaviors of past tropical cyclones (TCs) for the purpose of developing the diagnosis of T-number 0.5 (T0.5). The results indicate that T0.5 diagnosis is valid for satellite image analysis for TCs in the early developing stage (early stage Dvorak analysis: EDA). Organized convective cloud systems (OCCSs) diagnosed as T0.0 or T0.5 can be recognized as follows:

- Most OCCSs are not yet determined as tropical depressions (TDs) when they are first diagnosed as T0.0.
- OCCSs are likely to be determined as TDs when they are first diagnosed as T0.5.

In summer 2007, based on the above results and Kishimoto et al. (2007), JMA revised EDA. The main part of this revision involved the addition of T0.5 diagnosis to the former EDA, which consisted of OCCS detection, T1.0 diagnosis and T1.5/2.0 diagnosis. In addition, JMA revised the criteria for determining the TC grade using EDA results. Analysis of TCs in the early developing stage using the revised EDA is explained through the example of the TD that became USAGI (0705).

1. Introduction

Since 2001, the Japan Meteorological Agency (JMA) has been operating satellite image analyses for tropical cyclones (TCs) in the early developing stage (referred to below as *early stage Dvorak analysis* (EDA)). Kishimoto et al. (2007) verified the validity of EDA for TC analysis[1] in the early developing stage, comparing EDA results with JMA's TC analysis data over the five-year period from 2002 to 2006. Following the above study, JMA conducted a verification of past TC behavior for the purpose of developing the diagnosis of T-number 0.5 (T0.5). In summer 2007, based on these two verification results, JMA revised EDA and started its operational use for analysis of TCs in the early developing stage.

Section 2 describes T0.5 diagnosis and its verification results, and the revision of EDA is introduced in Section 3. Analysis of TCs in the early developing stage using the revised EDA is presented in Section 4, and Section 5 outlines the conclusion.

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[1] Refer to Section 2.1 of Kishimoto et al. (2007) for JMA's TC analysis.

2. Verification study for developing T0.5 diagnosis

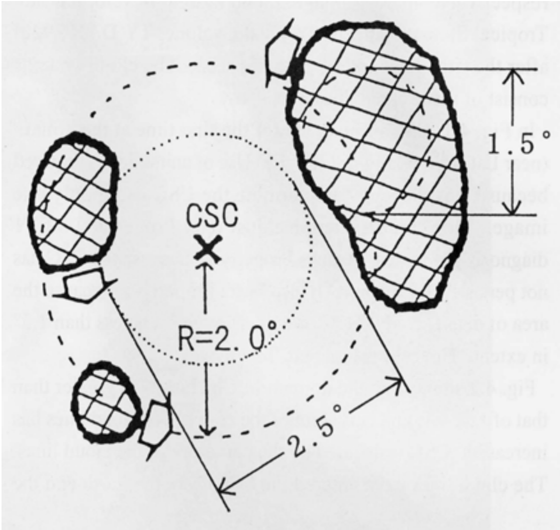
2.1 T0.5 Diagnosis

T0.5 diagnosis is conducted in the process of the T1.0 diagnosis proposed by Tsuchiya et al. (2000, 2001). Table 2.1 shows the five features of an organized convective cloud system (OCCS)[2] with an intensity of T1.0. In this diagnosis, an OCCS is diagnosed as T0.0 when it satisfies less than four of these features, and is T0.5 when it satisfies four features.

Table 2.1 Features of OCCSs diagnosed as T1.0

The figure on the right illustrates an OCCS diagnosed as T1.0.

	Tsuchiya et al. (2000, 2001)
1	A convective cloud system has persisted for 12 hours or more.
2	The cloud system has a CSC defined within a diameter of 2.5° latitude or less.
3	The CSC has persisted for six hours or more.
4	The cloud system has an area of dense, cold (-31°C or colder) that appears less than 2° latitude from the center.
5	The above overcast is more than 1.5° latitude in diameter.



2.2 Verification

First, T0.5 diagnosis was experimentally conducted using EDA data from 2002 to 2006. The results were then compared with TCs on JMA's surface weather charts to verify the following points in the same way as in Kishimoto et al. (2007)[3]:

- Development of OCCSs diagnosed as T0.0 (T0.0-OCCSs) or T0.5 (T0.5-OCCSs) to TCs
- Timing of the first diagnosis of OCCSs as T0.0 (FDT0.0) or T0.5 (FDT0.5) and their development to TCs.

Table 2.2 shows the TC grades used for the verification; tropical depression for which no warning was issued (NTD), tropical depression for which warnings were issued (WTD) and tropical storm (TS).

[2] An OCCS is defined in this paper as a convective cloud system with a cloud system center (CSC). CSCs are explained in Section 2.2 of Kishimoto et al. (2007).

[3] Refer to Section 3.1 of Kishimoto et al. (2007) for details of the verification.

Table 2.2　TC grades used for the study

NTD	TCs with definite cyclonic surface wind circulation and max. winds of less than Force 7 on the Beaufort scale (less than 28 kt)
WTD	TCs with definite cyclonic surface wind circulation and max. winds of Force 7 (28-33 kt)
TS	TCs with definite cyclonic surface wind circulation and max. winds of Force 8 or 9 (34-47 kt)

Table 2.3 shows the percentages of T0.0- or T0.5-OCCSs that developed to NTDs, WTDs or TSs, and the average periods from FDT0.0 or FDT0.5 to the first determination as TSs (FDTS). This table also shows those of T1.0-, T1.5- and T2.0-OCCSs for comparison.

It indicates the following:

- The percentages of T0.0- and T0.5-OCCSs that developed to TSs were 26% and 35% respectively.　The percentage for T0.5-OCCSs was higher than that for T0.0.
- The average periods from FDT0.0 and FDT0.5 to FDTS were 2.4 and 2.1 days respectively. These results correspond closely to the model for TC development shown by Dvorak (1984).

The results suggest that T0.5 diagnosis is valid for EDA.

Table 2.3　Percentages of T0.0- and T0.5-OCCSs that developed to NTDs, WTDs and TSs, and the average periods from FDT0.0 and FDT0.5 to FDTS from 2002 to 2006
Values for T1.0, T1.5 and T2.0 shown by Kishimoto et al. (2007) are included for comparison.

T-number	Number of OCCSs	Percentage (%) of OCCSs that reached each class			Average period (days) from first diagnosis as each T-number to the first determination as TSs (FDTS)
		NTD	WTD	TS	
T0.0	363	45	34	26	2.4
T0.5	267	64	47	35	2.1
T1.0	188	89	78	61	1.4
T1.5	112	97	95	79	0.8
T2.0	41	100	100	98	0.4

Table 2.4 shows the percentages of OCCSs that developed to NTDs or WTDs before, at and after FDT0.0 and FDT0.5, as well as the values for FDT1.0, FDT1.5 and FDT2.0 for comparison. It indicates the following:

- Few (4%) OCCSs were determined as NTDs before FDT0.0, while a significant number (24%) were determined as NTDs before FDT0.5.
- Few (5%) OCCSs were determined as WTDs before FDT0.5.

These results suggest that OCCSs are likely to be determined as NTDs at FDT0.5 in many cases.

Table 2.4 Percentages of OCCSs that developed to NTDs and WTDs before, at and after the first diagnosis as T0.0 and T0.5 from 2002 to 2006.
The values for T1.0, T1.5 and T2.0 shown by Kishimoto et al. (2007) are included for comparison.

T-number	Number of OCCSs	Percentage (%)					
		NTD			WTD		
		before	at	after	before	at	after
0.0	363	4	11	30	1	1	32
0.5	267	24	8	33	5	3	39
1.0	188	40	34	15	11	19	47
1.5	112	84	13	1	42	38	14
2.0	41	100	0	0	81	17	2

3. Revision of EDA

The main part of the revision involves the addition of T0.5 diagnosis to the former EDA[4], which consisted of OCCS detection, T1.0 diagnosis and T1.5/2.0 diagnosis. In addition, JMA revised the criteria for determining the TC grade using the verification results shown in Tables 2.3 and 2.4. Table 3.1 shows the criteria for determining the TC grade using T-numbers diagnosed through the new EDA compared to those diagnosed with the previous version. The criteria are based on the likelihood of OCCSs being determined as NTDs or WTDs at the time and the possibility of their development to TS status in the future. The former is prepared using the percentages of OCCSs that developed to NTDs or WTDs before or at their first diagnosis as the T-numbers in Table 2.4. The terms *unlikely*, *likely* and *highly likely* indicate percentages of lower than 30%, 30 to 70% and higher than 70% respectively. The latter is prepared using the percentages of OCCSs that developed to TSs in Table 2.3. The terms *poor*, *fair* and *high* indicate percentages of lower than 40%, 40 to 70% and higher than 70% respectively.

[4] Refer to Section 2.2 of Kishimoto et al. (2007) for the former EDA.

Table 3.1 Criteria for the determination of TC grade using T-numbers diagnosed through the new EDA compared to those diagnosed through the old EDA

<table>
<tr><th></th><th colspan="3">New EDA</th><th>Old EDA</th></tr>
<tr><th>T-number</th><th>Likelihood of being determined as NTDs at the time</th><th>Likelihood of being determined as WTDs at the time</th><th>Possibility of development to TSs in the future</th><th>Possibility of development to TSs in the future</th></tr>
<tr><td>0.0</td><td>Unlikely</td><td rowspan="2">Unlikely</td><td rowspan="2">Poor</td><td rowspan="2">Poor</td></tr>
<tr><td>0.5</td><td>Likely</td></tr>
<tr><td>1.0</td><td rowspan="3">Highly likely</td><td>Likely</td><td>Fair</td><td rowspan="3">High</td></tr>
<tr><td>1.5</td><td rowspan="2">Highly likely</td><td rowspan="2">High</td></tr>
<tr><td>2.0</td></tr>
</table>

4. Analysis of TCs in the early developing stage using the revised EDA

In order to analyze TCs in the early developing stage, JMA firstly diagnoses their T-number through the revised EDA and then determines their TC grade using the T-number, surface observation data, QuikSCAT data and numerical weather prediction (NWP) data in a comprehensive manner. As an example, analyses of the TD that became USAGI (0705) are described in Section 4.1.

4.1 Analyses of the pre-USAGI (0705) TC

An OCCS was initially detected at 00 UTC on 27 July 2007. It developed to a WTD at 18 UTC the same day, and was expected to develop to a TS within 24 hours (ExpT) at 06 UTC the next day. It then developed to a TS and was designated the name USAGI at 06 UTC on 29 July.

Figures 4.1, 4.2 and 4.3 show Asia-Pacific surface analyses (ASAS) and satellite images onto which the cloud system center (CSC) of the OCCS, NWP's surface winds and isobars are superimposed. The images represent 00 UTC on 27 July, 18 UTC on 27 July and 06 UTC on 28 July respectively. Figure 4.4 shows composites of satellite images and QuikSCAT data at 19 UTC on 27 July and 09 UTC on 28 July. All figures and data here are based on operational data rather than post-analysis data.

00 UTC, 27 July (Figure 4.1)

After 18 UTC on 26 July, a convective cloud system developed rapidly. At 00 UTC the next day, this cloud system was detected as an OCCS and satisfied four of the features (excluding the third) in Table 2.1, resulting in T0.5 status. This meant that the cloud system was likely to be determined as an NTD. In this case, it was determined as a low pressure area (LPA)[5] in ASAS since there were no available data to diagnose its TC grade except the EDA result.

At 06 UTC and 12 UTC the same day, the OCCS was also diagnosed as T0.5, since there were no data to confirm its development to a TC except the EDA result. It remained an LPA in ASAS.

18 UTC, 27 July (Figure 4.2, Figure 4.4 (a))

At 18 UTC on 27 July, the OCCS satisfied all five features and was diagnosed as T1.0. This result meant that the cloud system was highly likely to be determined as an NTD and likely to be determined as a WTD. In this case, the system was determined as a WTD in ASAS, since the latest NWP data presented a corresponding cyclone and also indicated signs of development. QuikSCAT data without rain flags indicated winds of over 25 kt around it at 19 UTC the same day. These data suggested stronger winds near its CSC and supported its determination as a WTD.

06 UTC, 28 July (Figure 4.3, Figure 4.4 (b))

At 06 UTC on 28 July, the OCCS was diagnosed as T1.5 because its cyclonic circulation became more evident from satellite imagery. This result meant that the system was highly likely to be determined as a WTD and also had a high possibility of developing to a TS. In this case, it was determined as an ExpT in ASAS because NWP clearly indicated its development within 24 hours. QuikSCAT data without rain flags at 09 UTC the same day indicated that it had a definite cyclonic circulation and winds of over 30 kt near its CSC.

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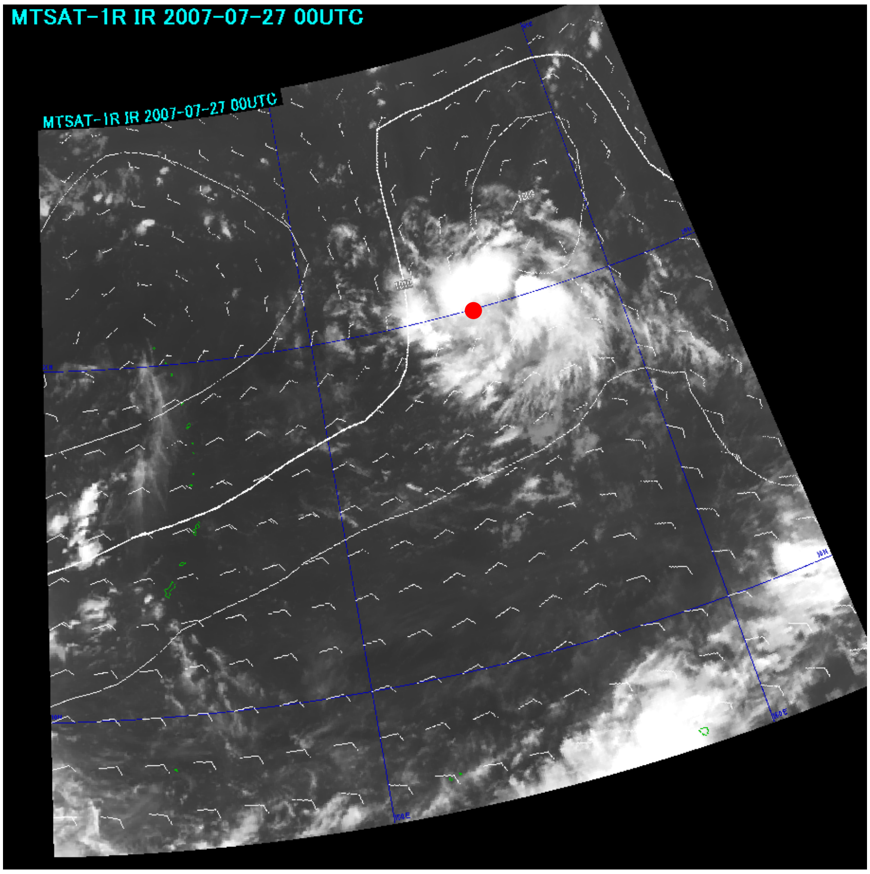
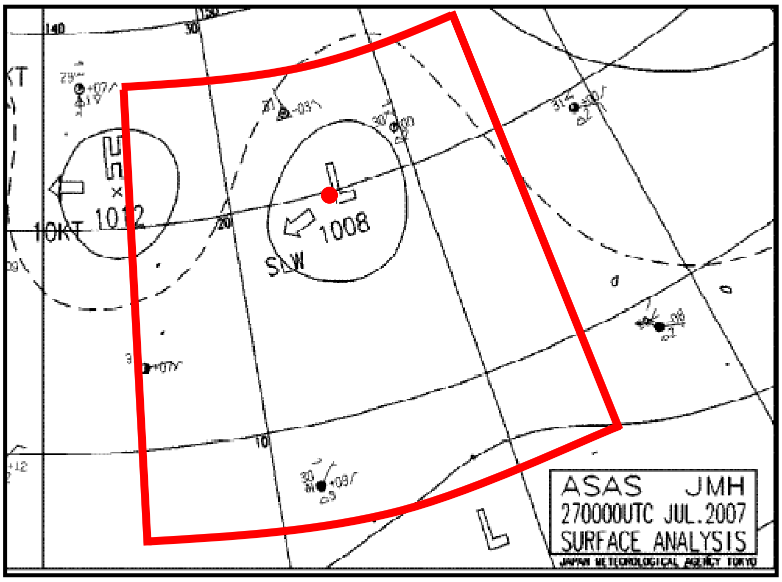
[5] An LPA is a TC without definite cyclonic surface wind circulation where surface air pressures are lower than those of the surroundings.

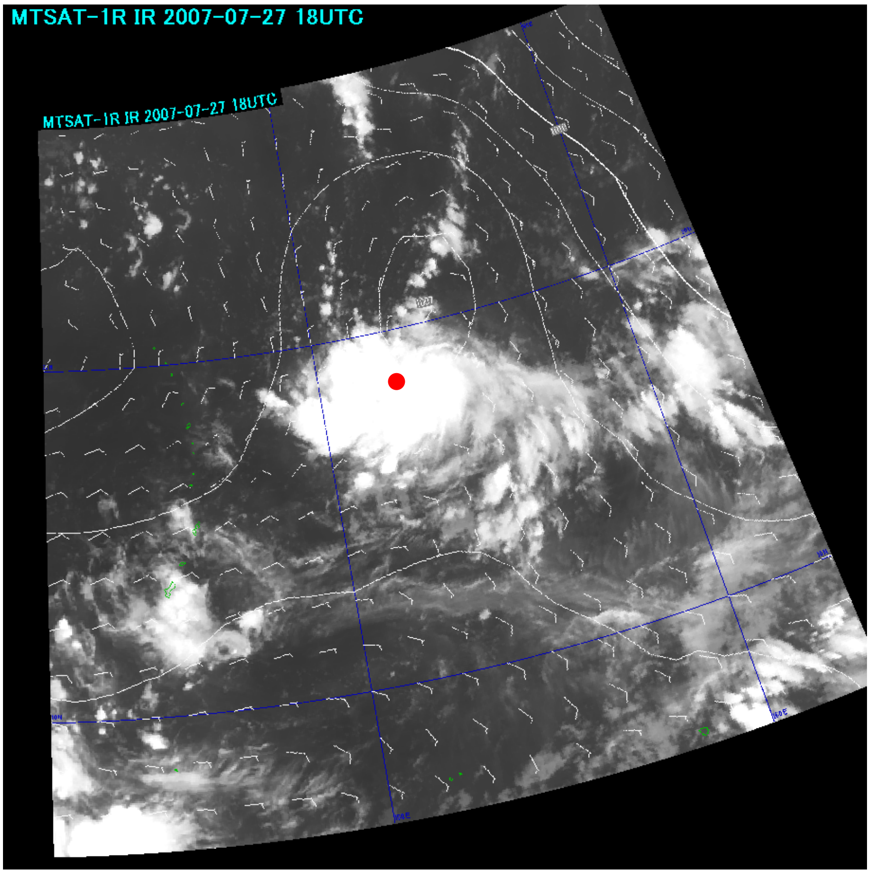


(a) Satellite image
The white arrows and lines and the red dot indicate NWP's surface winds, surface isobars and the CSC position of the OCCS respectively.



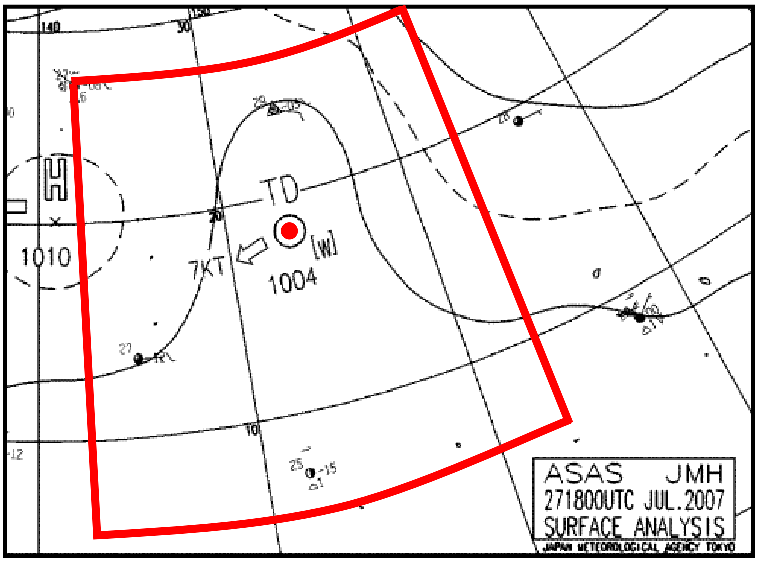
(b) Surface Analysis
The red dot indicates the CSC position of the OCCS. The area surrounded by the red line shows the coverage area of the above satellite image.

Figure 4.1 Satellite image and surface analysis for 00 UTC on 27 July 2007



(a) Satellite image

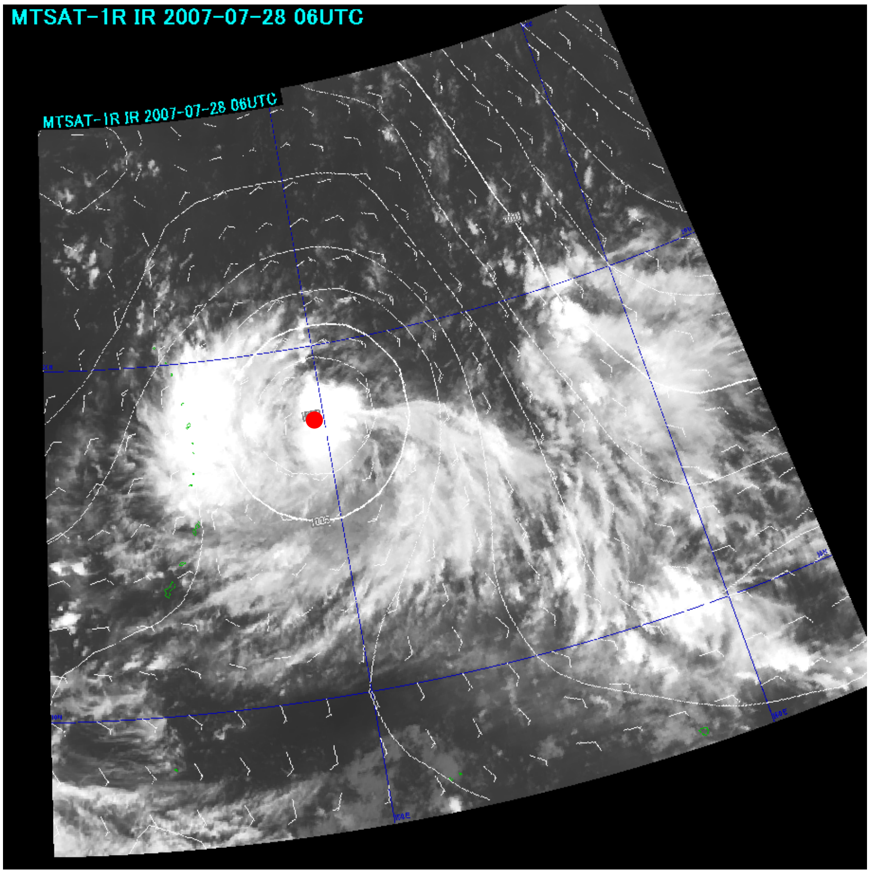
The white arrows and lines and the red dot indicate NWP's surface winds, surface isobars and the CSC position of the OCCS respectively.



(b) Surface Analysis

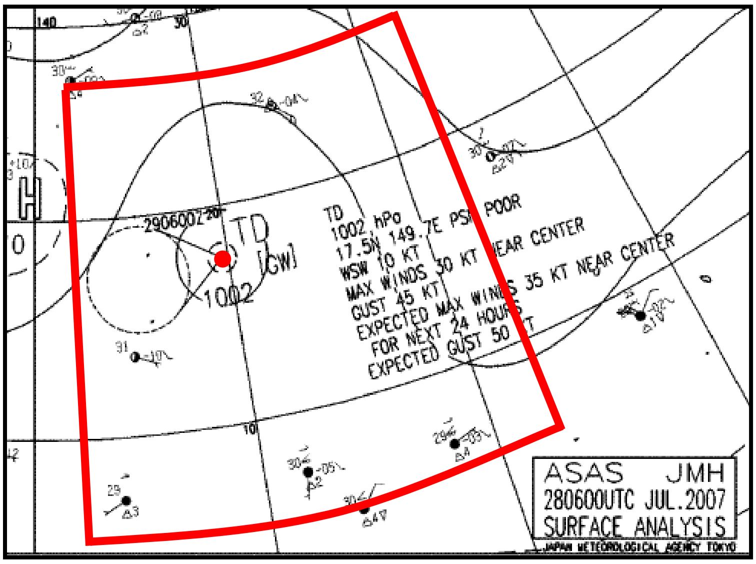
The red dot indicates the CSC position of the OCCS. The area surrounded by the red line shows the coverage area of the above satellite image.

Figure 4.2 As Figure 4.1, but for 18 UTC on 27 July 2007



(a) Satellite image

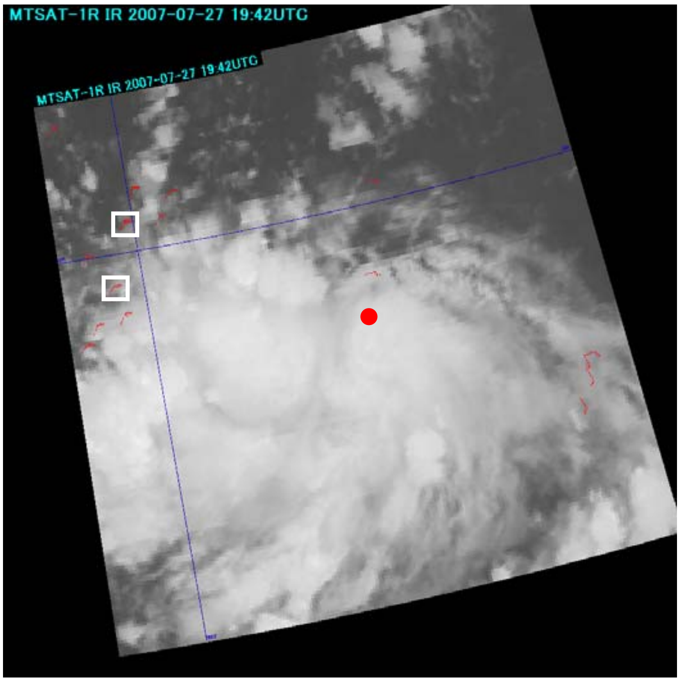
The white arrows and lines and the red circle indicate NWP's surface winds, surface isobars and the CSC position of the OCCS respectively.



(b) Surface Analysis

The red indicates the CSC position of the OCCS. The area surrounded by the red line shows the coverage area of the above satellite image.

Figure 4.3 As figure 4.1, but for 06 UTC on 28 July 2007



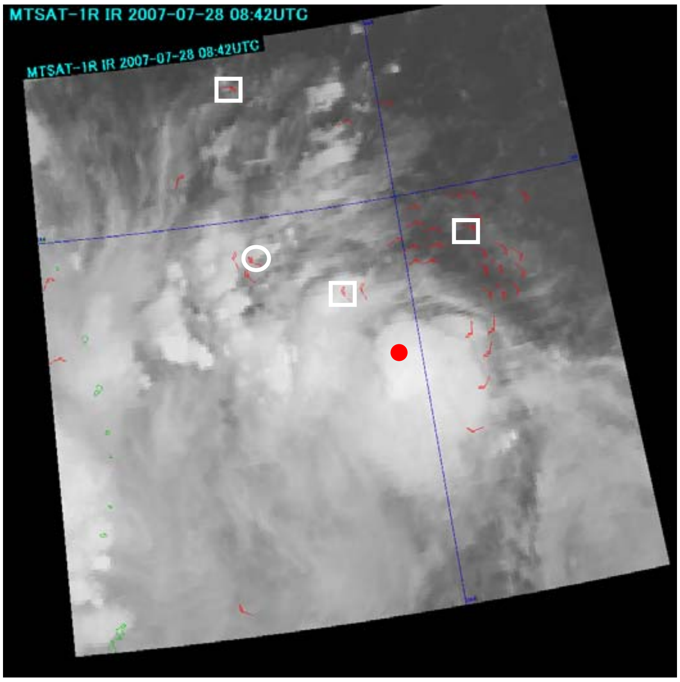


Figure 4.4 Satellite image and QuikSCAT winds of over 20 kt without rain flags (red arrows) at 20 UTC on 27 July (upper) and 09 UTC on 28 July (lower)

Each red dot indicates the CSC position at 18 UTC on 26 July (upper) and 06 UTC on 27 July (lower). Red arrows within circles and squares indicate winds of 25 to 30 kt and 30 to 35 kt respectively.

5. Conclusion

The revised EDA is one of the most important tools JMA uses to analyze TCs in the early developing stage. Table 5.1 shows typical examples of TC analysis in the early developing stage. Both Dvorak analysis and EDA are subjective methods, and their results depend on the operators involved. For this reason, their objectivization remains an issue to be solved.

Table 5.1 Typical examples of TC analysis in the early developing stage using surface observation data, QuikSCAT data, satellite imagery and NWP data, depending on the T-number of the OCCS.

<table>
<tr><th>T-number</th><th>Determination as TD</th><th>Determination as WTD</th><th>Determination as ExpT</th></tr>
<tr><td>0.0</td><td>It is monitored as a potential TD.</td><td rowspan="2">It is monitored as a potential WTD.</td><td rowspan="2">It is monitored as a potential ExpT.</td></tr>
<tr><td>0.5</td><td>If it has definite cyclonic wind circulation and winds of near Beaufort Force 6 or more, it is determined as a TD.</td></tr>
<tr><td>1.0</td><td rowspan="3">It is determined as a TD.</td><td>If it has winds of near Beaufort Force 7 or more, it is determined as a WTD.</td><td>If it has winds of near Beaufort Force 7 or more and NWP predicts the definite development within 24 hours, it is determined as an ExpT.</td></tr>
<tr><td>1.5</td><td rowspan="2">It is determined as a WTD.</td><td>If NWP predicts the development within 24 hours, it is determined as an ExpT.</td></tr>
<tr><td>2.0</td><td>It is determined as an ExpT.</td></tr>
</table>

References

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