

# Comparative Study on Organized Convective Cloud Systems detected through Early Stage Dvorak Analysis and Tropical Cyclones in Early Developing Stage in the Western North Pacific and the South China Sea

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## **Abstract**

The Japan Meteorological Agency (JMA) has been operating the satellite image analysis for tropical cyclones (TCs) in early developing stage such as tropical depressions (TDs) since 2001 to detect them and diagnose their possibility to develop into tropical storms (TSs). The analysis, which is based on Dvorak (1984), is referred to the early stage Dvorak analysis (EDA) in this report. Comparing organized convective cloud systems (OCCSs) detected through EDA with TCs on weather charts from 2002 to 2006, the detected OCCSs can be acknowledged as follows:

- TDs usually have an OCCS detected through EDA, while low pressure areas (LPAs) do not.
- OCCSs determined as the T-number of less than 1.0 have considerable possibility (about 50%) to develop into TDs with the 10-minute maximum sustained wind (MSW) of less than Beaufort Force 7. On the other hand, few (about 5%) OCCSs develop into TDs with MSW of less than Force 7 before the first detection of OCCSs.
- OCCSs determined as the T-number of 1.0 (T1.0) have very high possibility (about 80%) to develop into TDs with MSW of Force 7 and high possibility (about 60%) to develop into TSs. Before or at the first T1.0 determination, many (about 75%) of them develop into TDs of with MSW of less than Force 7.
- OCCSs determined as T1.5 have very high possibility (about 80%) to develop into TSs. Before or at the first T1.5 determination, many (about 80%) of them develop into TDs with MSW of Force 7.
- Most (near 100%) of OCCSs determined as T2.0 develop into TSs.

## **1. Introduction**

Geostationary meteorological satellite imagery is one of the most important tools

for analyzing tropical cyclones (TC)<sup>1</sup> in the tropical ocean which has few synoptic surface observations. Since 2001, the satellite image analysis has been operated for TCs in early developing stage by the Meteorological Satellite Center (MSC)<sup>2</sup> of the Japan Meteorological Agency (JMA), in addition to the satellite image analysis for ones developed to approximate tropical storm (TS) intensity or higher which has been conducted for more than 20 years. Both analyses are based on Dvorak (1984). In this report, the former one is referred to as the early stage Dvorak analysis (EDA), while the latter one is referred to as the Dvorak analysis.

The results of EDA are used for the JMA headquarters (JMAHQ) not only to detect TCs in weather map analysis but also to diagnose their possibility to develop to TS intensity. They have been archived since 1999 when MSC started the experimental operations of EDA. So far, several studies using these archives have been already conducted. Ueno (2002) and Terasaka et al. (2007) verified the diagnosis of the development into TSs using the 2-year data from 2000 to 2001, and the 6-year data from 2000 to 2005, respectively. In addition, Bessho et al. (2006) investigated the frequency of occurrence, geographical distribution, and duration of organized convective cloud system (OCCSs)<sup>3</sup> using the 4-year data from 2002 to 2005. The main purpose of these studies was to verify the diagnosis of the development into TSs. Therefore, this study mainly focuses on the verification of EDA with respect to the detection of TCs in early developing stage by comparing OCCSs detected through EDA with TCs on weather charts.

Hereinafter, the TC analysis of JMAHQ and EDA of MSC are introduced in Section 2. Then, the verifications and their discussions are described in Section 3, and finally summarized in Section 4.

## **2. TC analysis of JMA**

### **2.1 TC analysis of JMAHQ**

JMAHQ analyze TCs in the western North Pacific and its adjacent seas including the South China Sea to issue weather information for ships such as marine warning and Asia-Pacific surface analysis (ASAS). At the same time, as the Regional Specialized

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1 In this report, "tropical cyclone (TC)" is used as a generic term that includes "low pressure area (LPA)", "tropical depression (TD)", "tropical storm (TS)", "severe tropical storm (STS)" and "typhoon (TY)". LPA, TD, TS, STS and TY are defined in WMO (2005).

2 The operation of both analyses is going to be transferred from MSC to the JMA headquarters in 2007.

3 In this report, an "organized convective cloud system (OCCS)" is defined as a convective cloud system with a cloud system center (CSC). "CSC" is explained in Section 2.2. A convective cloud system is seen as a group of convective cloud areas including convective cloud bands and lines in satellite imagery.

Meteorological Center (RSMC) with specialized activities in analysis and forecasting of TCs in the above area within the framework of WMO, JMAHQ analyze TCs of TS intensity or higher and ones expected to attain to TS intensity within 24 hours (ExpT) in the area, and provides the analysis information for the National Meteorological Services concerned.

Fig. 2.1 shows the flow of JMA's operation of TC analysis. Out of TCs with definite cyclonic surface wind circulation, ones with less than Beaufort Force 8 (less than 34kt) in 10-minute maximum sustained wind (MSW), Force 8 and 9 (34-47kt), Force 10 and 11 (48-63kt), and Force 12 (64kt or more) are determined as tropical depressions (TDs)<sup>4</sup>, TSs, severe tropical storms (STSs), and typhoons (TYs), respectively.

Next, TDs expected to attain to TS within 24 hours are determined as ExpTs. Furthermore, TDs except ExpTs are discriminated with respect to MSW of Force 7 (28-33kt), because JMAHQ issue marine warning for the TDs with MSW of Force 7, as well as ExpTs and TCs of TS intensity or higher. In this report, TDs with MSW of Force 7 (28-33kt) are referred to as warning-issued TD (WTD), while TDs with MSW of less than Force 7 (less than 28kt) are referred to as no-warning-issued TD (NTD).

On the other hand, TCs with lower surface pressure than surrounding area and without definite surface cyclonic wind circulation are determined as low pressure area (LPA).

In order to detect and classify TCs, JMAHQ use meteorological data such as surface observations (SYNOP, SHIP, and BUOY data), geostationary meteorological satellite images and their analysis data, QuikSCAT wind retrievals, etc. in a comprehensive manner. Among them, "satellite image analysis data" means EDA data

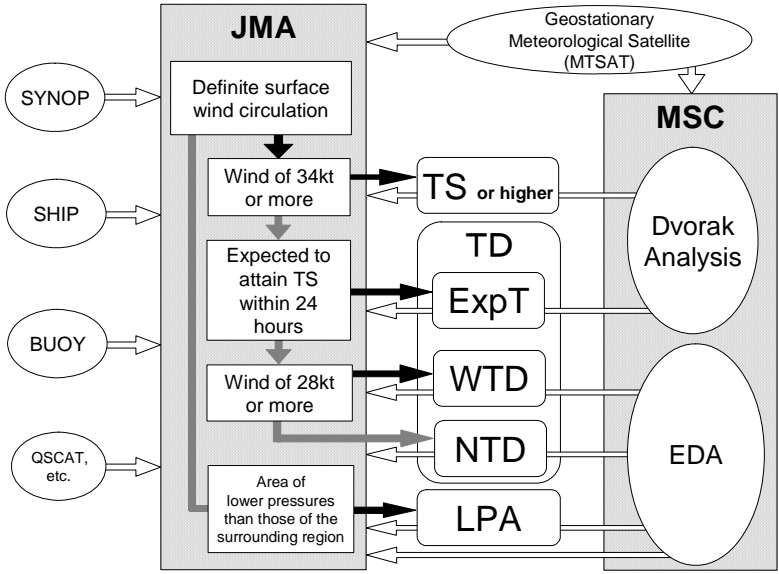


Fig. 2.1 Flow of JMA's operation of TC analysis. White arrows indicate data flow, and black and grey arrows indicate "yes" and "no", respectively.

4 With respect to the formation of TDs, JMA determines TCs as TD at the first analysis of around Force 6 (22-27kt) within them.

and the Dvorak analysis data. EDA, surveyed in this study, is explained in Section 2.2.

In addition, JMAHQ post-analyze TCs which attained to TS intensity or higher during the period from the TD formation to the dissipation of TDs or transformed extratropical cyclones, combining the operational analysis data with additional data received later in order to issue Best Track data. JMAHQ also post-analyze TDs and LPAs to issue the JMA weather chart. Table 2.1 shows the items of the JMAHQ's TC analysis and the main products based on their analyses which are issued internationally.

Table 2.1 Items of TC analysis and the main products based on the analysis data which are issued internationally by JMAHQ. PS, SP, DR, CP and MSW indicate center position, speed and direction of movement, central pressure, and 10-minute maximum sustained wind, respectively.

	Items of analysis	Frequency of analysis	Main products issued Internationally
<b>Operational analysis</b>			
TS or higher	PS, SP, DR, CP, MSW, 30kt and 50kt radius	3hourly	RSMC TC advisory SafetyNET TC information
ExpT	PS, SP, DR, CP, MSW		
WTD			
NTD	PS, SP, DR, CP	6hourly	Marine warning Asia-Pacific Surface Analysis
LPA	PS, CP		
<b>Post-analysis</b>			
TS or higher	PS, SP, DR, CP, MSW, 30kt and 50kt radius	6hourly	Best track  JMA weather chart
TD before/after TS	PS, CP		
Other TD			
LPA			

## 2.2 Early stage Dvorak analysis (EDA)

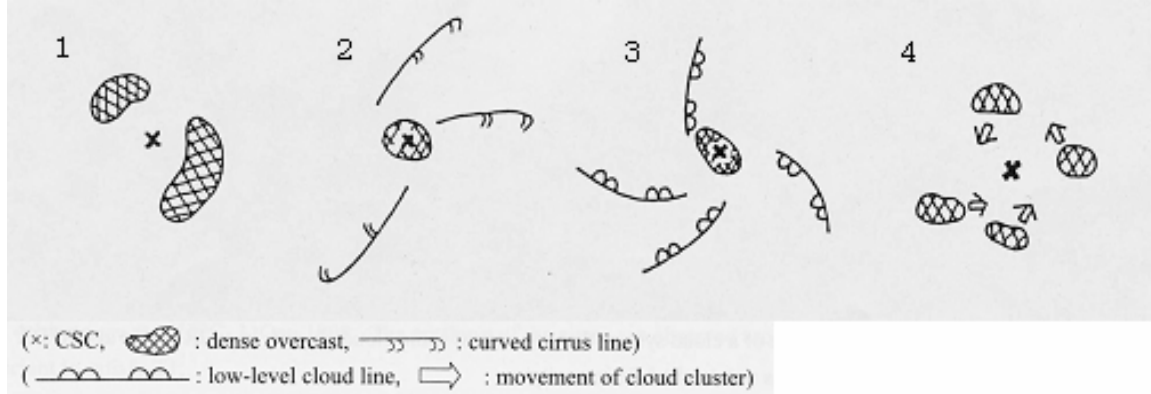
EDA consists of three steps: the detection of OCCSs, the classification of T-number 1.0 (T1.0), and the classification of T-number 1.5 and 2.0 (T1.5/2.0).

The first step of EDA is the detection of OCCSs which are convective cloud systems with a cloud system center (CSC). The CSC features proposed by Tsuchiya et al. (2000, 2001) are used in this detection. Table 2.2 shows the CSC features of Tsuchiya et al. (2000, 2001) and Dvorak (1984). In consideration of the recent improvement of satellite observation, Tsuchiya et al. (2000, 2001) supplemented the CSC features of Dvorak (1984), basically adopting them from the result of Zehr (1992) that the features of convective cloud systems developing into TSs in the western North Pacific followed them closely. Besides the 3 features of Dvorak, Tsuchiya et al. added a feature which is determined using animated satellite imagery. If a CSC can be

determined within a convective cloud system, the cloud system is regarded as an OCCS.

Table 2.2 CSC features of Tsuchiya et al. (2000, 2001) (left) and Dvorak (1984) (right). The lower figure illustrates the CSC features proposed by Tsuchiya et al.

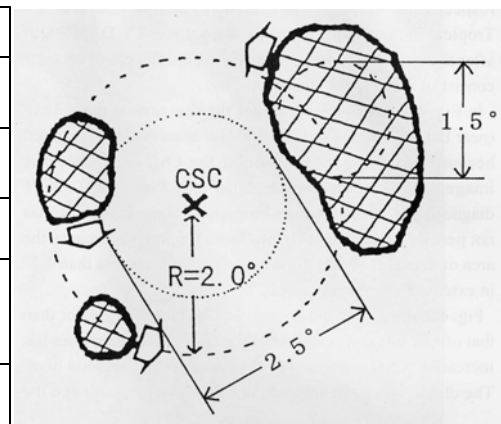
	Tsuchiya et al. (2000, 2001)	Dvorak (1984)
1	Curved band, a dense (-31°C or colder) overcast band that shows some curvature around a relatively warm (cloud minimum) area. It should curve at least one-fifth the distance around a 10° log spiral. Cirrus, when visible, will indicate anticyclonic shear across the expected CSC.	
2	Curved cirrus lines indicating a center of curvature within or near a dense, cold (-31°C or colder) overcast.	
3	Curved low cloud lines showing a center of curvature within 2° of a cold (-31°C or colder) cloud mass.	
4	Cumulonimbus clusters rotating cyclonically on animated imagery	None



As the next step of EDA, the T1.0 classification is conducted for detected OCCSs. The OCCS features proposed by Tsuchiya et al. (2000, 2001) are used in this classification. Table 2.3 shows the 5 features of OCCSs determined as T1.0, into which those of Dvorak (1984) are divided. If an OCCS satisfies all 5 features, it is determined

Table 2.3 Features of OCCSs determined as T1.0. The right figure illustrates an OCCS determined 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 persists for 6 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.



as T1.0. Otherwise it is determined as the T-number of less than 1.0.

For OCCSs determined as T1.0 consecutively, the T1.5/2.0 classification is conducted. Regarding this classification, MSC supplemented the method of Dvorak (1984), which had no detailed description about it, with some rules. In this classification, an OCCS is observed with respect to the time variation in the organization such as the curvature and length of convective curved bands and the cyclonical rotation of convective cloud areas. If it is determined to be more organized than at the previous analysis, 0.5 is added to the previous T-number. If it is determined to be less organized, 0.5 is subtracted from the previous T-number, considering the T-number not to be less than 1.0. It is to be noted that this classification is conducted referring the PT chart of Dvorak (1984) to ensure the continuity to the Dvorak analysis. The contents and an example of EDA are shown in Table 2.4 and Fig. 2.2, respectively.

Table 2.4 Contents of EDA

Frequency	6hourly (00, 06, 12, 18UTC)	
Procedure	1. OCCS detection	Dvorak (1984) supplemented by Tsuchiya et al. (2000, 2001)
	2. T1.0 classification	
	3. T1.5/2.0 classification	Dvorak (1984) supplemented by MSC
Contents	CSC position, T-number	

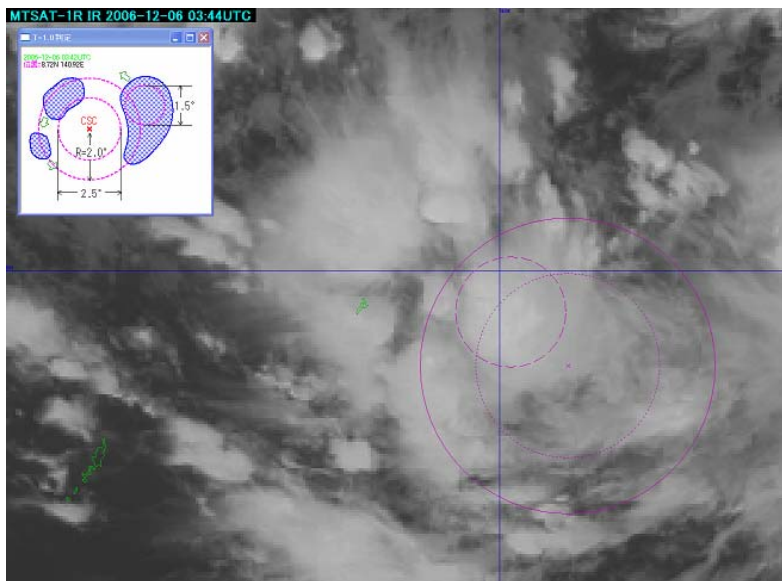


Fig. 2.2 Screen capture of EDA for a tropical disturbance over the sea east of Yap Island at 04UTC on 6 December 2006

### 3. Verifications and discussions

In this section, OCCSs detected through EDA are compared with TCs on weather charts to verify the following issues:

- Correspondence of OCCSs to TCs (Section 3.2)
- Development of OCCSs into TCs (Section 3.3)
- Timing of the detection of OCCSs and the development of TCs (Section 3.4)

### 3.1 Preparation for the verifications

#### *Classification of TCs*

Table 3.1 describes the classification of TCs used for the verifications.

Table 3.1 Classification of TCs

Grade	
LPA	TCs without definite cyclonic surface wind circulation where surface air pressure are lower than those of the surrounding
NTD	TCs with definite cyclonic surface wind circulation and MSW of Beaufort scale of less than Force 7 (less than 28kt)
WTD	TCs with definite cyclonic surface wind circulation and MSW of Force 7 (28-33kt)
TS	TCs with definite cyclonic surface wind circulation and MSW of Force 8 and 9 (34-47kt)

#### *Data used for the verifications*

The 5-year data of OCCSs and TCs (NTDs, WTDs, and LPAs) from 2002 to 2006 are used for the verifications due to the homogeneity of OCCS data<sup>5</sup>. Operational analysis data are used for OCCSs, NTDs, WTDs, and LPAs, while post-analysis data for TSs. The followings are reasons why operational analysis data are used except for TSs:

- OCCS data are not post-analyzed.
- TDs are classified into NTDs and WTDs only in the operational analysis.
- Post-analysis data of LPAs are not archived in digital format.

#### *Matching of OCCSs with TCs*

In order to compare OCCSs with TCs on weather charts, a definition needs to be established for their matching. In these verifications, it is defined that an OCCS corresponds to a TC when the center position of the TC is within about 4° in latitude and longitude from the CSC. The basic concept of this definition is that an OCCS corresponds to a TC whose center position is within the domain of the OCCS. The domain is, in the verifications, limited to the area within about 4° in latitude and longitude from CSC, where primary convective cloud area forming an OCCS is seen using the 4<sup>th</sup> and the 5<sup>th</sup> features in Table 2.3.

#### *Definition of base time points*

Base time points are defined as described in Table 3.2. The numbers of OCCSs which reached each time point from 2002 to 2006 are also shown in the same Table.

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<sup>5</sup> Terasaka et al. (2007) reported that OCCS data have a gap between ones before and after 2002 due to the minor change of the EDA procedure in the year.

Table 3.2 Definition of base time points and the numbers of OCCSs which reached each time point

Base time point		Number of OCCSs
FDOCS	First detection of an OCCS	453
FDT10	First determination of an OCCS as T1.0	188
FDT15	First determination of an OCCS as T1.5	112 <sup>6</sup>
FDT20	First determination of an OCCS as T2.0	41 <sup>6</sup>
FDTs	First determination of an OCCS as TS	119

### 3.2 Correspondence of OCCSs to TCs

Fig. 3.1 shows the total numbers<sup>7</sup> analyzed as TCs on weather charts which had an OCCS detected through EDA from 2002 to 2006. Out of the total 2589, 809 and 512 analyses<sup>8</sup> of LPAs, NTDs and WTDs on weather charts, 587 (23%<sup>8</sup>), 611 (75%<sup>8</sup>) and 497 (97%<sup>8</sup>) analyses corresponded to OCCSs, respectively. These results reveal that many of NTDs and WTDs corresponded to OCCSs, while many of LPAs did not. Hereinafter, OCCS data are not verified for LPAs.

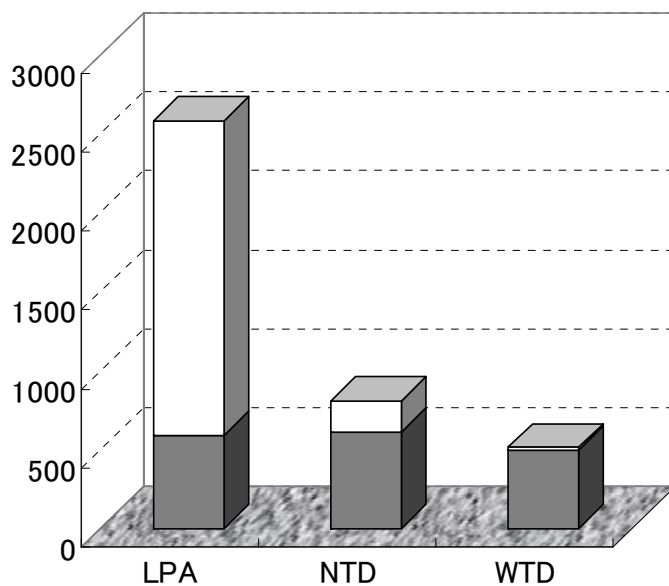


Fig. 3.1 Total number of analyses of TCs on weather charts with OCCSs (grey bars) and without OCCSs (white bars)

<sup>6</sup> Numbers of FDT15- and FDT20-reached OCCSs were less than that of FDTs-reached, because many OCCSs were determined as ExpT, for which EDA was terminated, before they reached FDT15.

<sup>7</sup> The analysis number of a TC and the detection number of an OCCS are counted for every analysis and detection in weather map analysis conducted four times a day (00, 06, 12 and 18UTC).

<sup>8</sup> These total analyses include those of weakening TCs, such as ones located over land, many of which did not have an OCCS. Therefore, the percentages of TCs only in early developing stage with an OCCS should be higher to some extent than those in this sentence.



### 3.3 Development of OCCSs into TCs

Fig. 3.2 shows the percentages of OCCSs which finally attained to NTD, WTD and TS out of all ones which reached each time point as follows:

- Out of all FDOCS-reached OCCSs, 47%, 34% and 26% finally attained to NTD, WTD, and TS, respectively.
- Out of all FDT10-reached ones, 89%, 78% and 61% attained.
- Out of all FDT15-reached ones, 97%, 95% and 79% attained.
- Out of all FDT20-reached ones, 100%, 100% and 98% attained.

They reveal the percentage of OCCSs which finally attained to TS was low before FDT10, while high at or after FDT10.

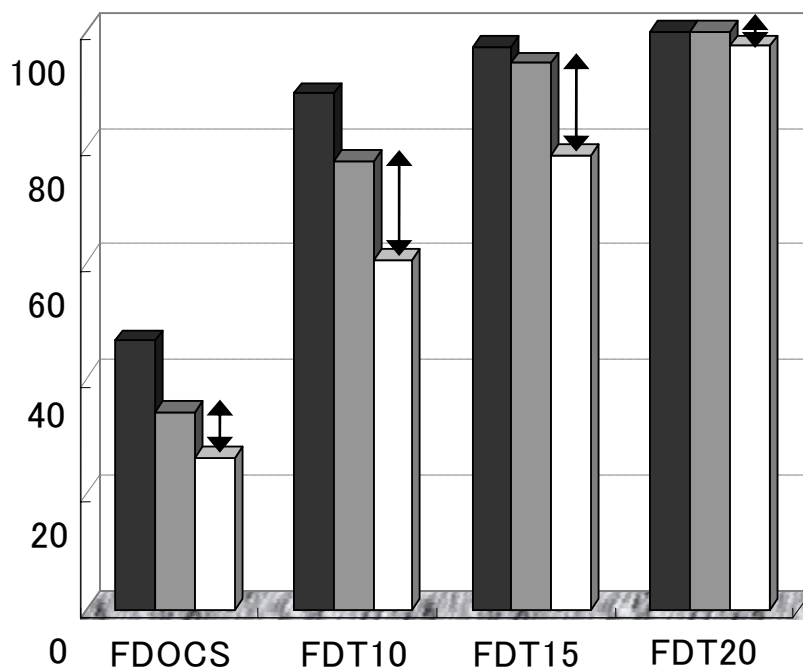


Fig. 3.2 Percentage (%) of OCCSs which finally attained to NTD (dark grey bars), WTD (light grey bars) and TS (white bars) out of all ones which reached each time point. Arrows indicate the percentages of ones which finally attained to WTD not TS.

### Discussion

This figure also shows that, with respect to the percentage of OCCSs which finally attained to WTD not TS, the percentages of FDT10- and FDT15-reached ones were higher than those of FDOCS- and FDT20-reached.

This result is firstly discussed by comparing the tracks of TS-attained and not-TS-attained OCCSs out of FDT10-reached ones (Figure 3.3). This figure reveals that many of not-TS-attained ones were located over the sea around the Philippines or in the South China Sea at FDT10, and then dissipated on or near land. Secondly, the percentages of TS-attained ones are compared between two groups: the group of OCCSs located to the west of 130°E (130W-OCCSs), relatively close to land area, at each time

point, and the other group of ones located to the east of 130°E (130E-OCCSs), relatively far from land area (Fig. 3.4).

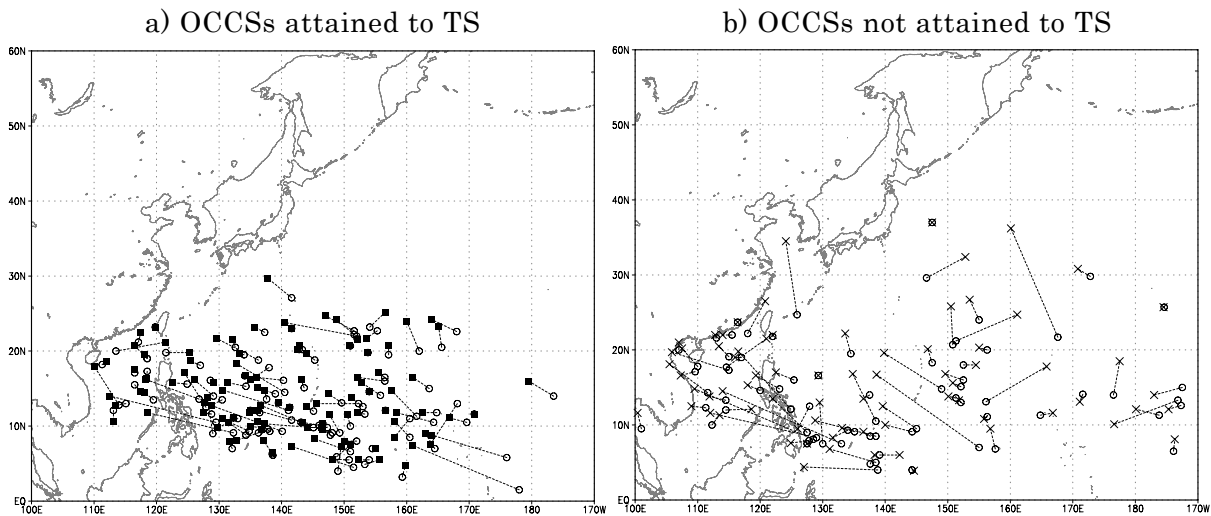


Fig. 3.3 Tracks of FDT10-reached OCCSs which finally attained to a) TS and b) not TS. Open circles, squares and crosses indicate the positions at FDT10, the determination as ExPT (the termination of EDA) and the dissipation, respectively.

The results are as follows:

- Regarding FDT10- and FDT15-reached OCCSs, 43% and 59% of 130W-OCCSs and 67% and 86% of 130E-OCCSs finally attained to TS, respectively. The differences between the two groups were relatively large (about 25%).
- Regarding FDOCS- and FDT20-reached OCCSs, 17% and 92% of 130W-OCCSs and 29% and 100% of 130E-OCCSs finally attained to TS, respectively. The differences between the two groups were relatively small (about 10%).

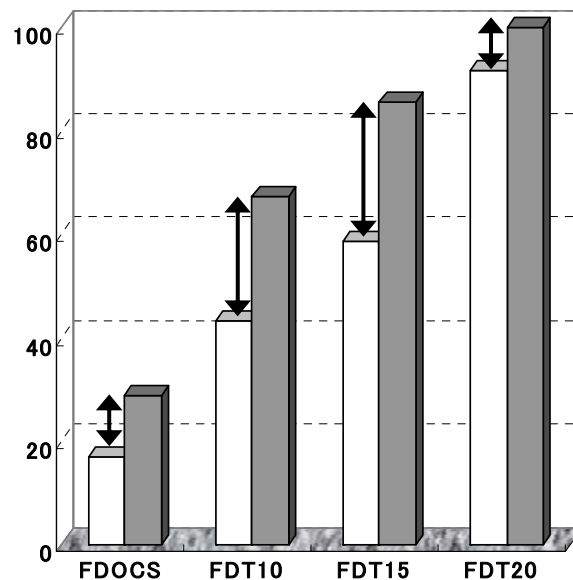


Fig. 3.4 Percentage (%) of OCCSs at each time point which finally attained to TS

White and grey bars indicate the percentages of 130W-, 130E-OCCSs, respectively. Arrows indicate the differences between those of 130W- and 130E-OCCSs.

The above comparative results reveal that it was a key factor to attain to TS for OCCSs especially at FDT10 or FDT15 to "be located far from land area".

### 3.4 Timing of the detection of OCCSs and the development of TCs

Fig. 3.5 shows the percentages of NTD- and WTD-attained OCCSs before, at, and after each time point. The results are as follows:

- 6% and 1% of FDOCS-reached OCCSs attained to NTD and WTD before FDOCS, respectively.
- 12% and 2% of FDOCS-reached OCCSs attained to NTD and WTD at FDOCS.
- 74% of FDT10-reached OCCSs attained to NTD before or at FDT10.
- 80% of FDT15-reached OCCSs attained to WTD before or at FDT15.
- 97% of FDT20-reached OCCSs attained to WTD before or at FDT20.

They reveal that many of FDT10-reached ones attained to NTD before and at FDT10, and many of FDT15-reached ones attained to WTD before or at FDT15.

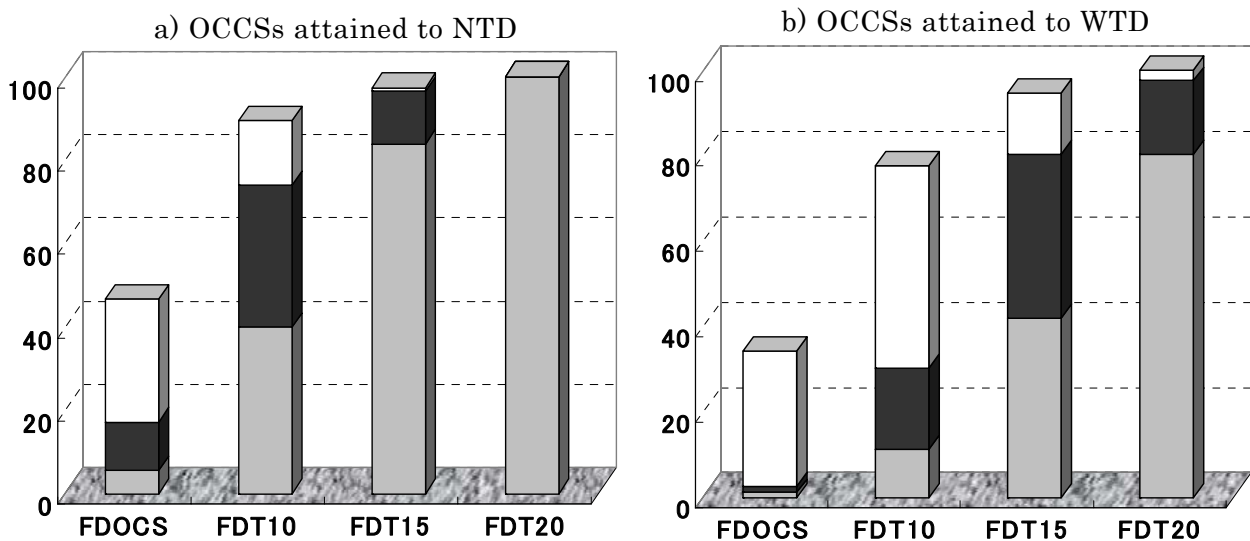


Fig. 3.5 Percentage (%) of OCCSs which attained to a) NTD and b) WTD before (light grey bars), at (dark grey bars), and after (white bars) each time point, respectively

Fig. 3.6 shows the average period from each time point (FDOCS, FDT10, FDT15, and FDT20) to FDTS: 2.3, 1.4, 0.8 and 0.4 days. This result agrees well with the model for the development of TCs shown by Dvorak (1984), and reveals that EDA is appropriate for analysis based on Dvorak.

### Discussion

In the process of this verification, it was found that 2 out of 119 TS-attained OCCSs from 2002 to 2006 were determined as ExpT before FDT10, and their positions at FDOCS were 19°N and 29°N, both in relatively high latitudes.

Therefore, the average period from each time point to FDTS is examined for three groups of OCCSs depending on latitude: the group of ones located to the south of  $10^{\circ}\text{N}$  at each time point (S-OCCSs), the group of ones located from  $10^{\circ}\text{N}$  to  $20^{\circ}\text{N}$  (M-OCCSs), and the group of ones located to the north of  $20^{\circ}\text{N}$  (N-OCCSs). In this regard, no OCCSs attained to TS which were located to the north of  $30^{\circ}\text{N}$  at each time point. The results are shown in Fig. 3.7 as follows:

- The average period from each time point (FDOCS, FDT10 and FDT15) to FDTS was 2.8, 1.9 and 1.2 days for S-OCCSs, while 1.7, 1.2 and 0.6 days for N-OCCSs, respectively. In particular, the average period from FDOCS to FDTS for N-OCCSs was about one day shorter than for S-OCCSs.
- Regarding the average period from FDT20 to FDTS, difference depending on latitude was relatively small.

These results reveal that OCCSs located in higher latitude, except FDT20-reached ones, had a tendency to develop to TS in a shorter time.

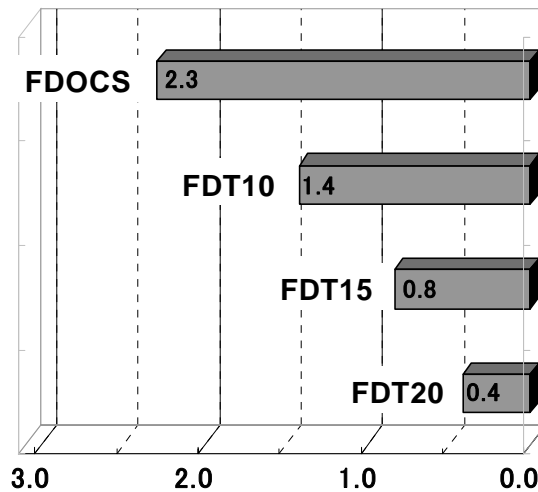


Fig. 3.6 Average period (days) from each time point to FDTS

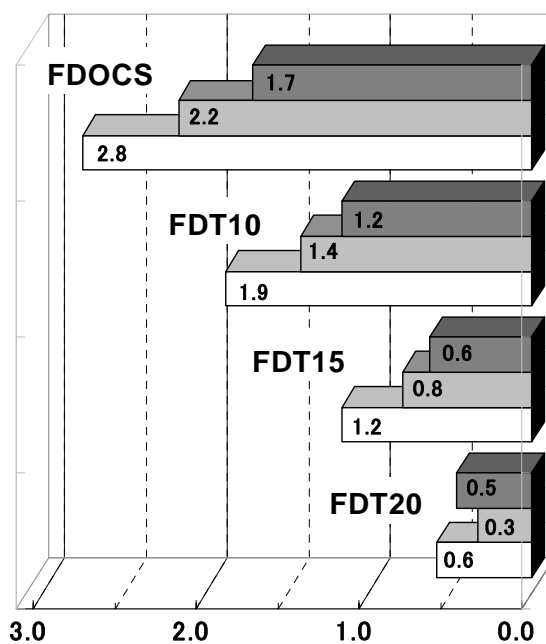


Fig. 3.7 Average period (days) from each time point to FDTS depending on latitude. White, light grey and dark grey bars indicate average periods for S-, M- and N-OCCSs, respectively.

#### 4. Summary of the study

The results of the study are summarized in Table 4.1. OCCSs can be acknowledged as follows from the verification results:

- NTDs and WTDs usually have an OCCS, while LPAs do not.
- OCCSs determined as the T-number of less than 1.0 have considerable possibility to attain to NTD. On the other hand, few OCCSs attain to NTD before FDOCS. They attain to TS in about 2.5 days after FDOCS on the condition that they develop steadily.
- OCCSs determined as the T-number of 1.0 have very high possibility to attain to WTD, and have high possibility to attain to TS. They usually attain to NTD before or at FDT10. They attain to TS in about 1.5 days after FDT10 on the condition that they develop steadily.
- OCCSs determined as the T-number of 1.5 have very high possibility to attain to TS. They usually attain to WTD before or at FDT15. They attain to TS in about 1.0 days after FDT15 on the condition that they develop steadily.
- Most of OCCSs determined as the T-number of 2.0 attain to TS. They attain to TS in about 0.5 days after FDT20.

In addition, the followings should be noted from the results of discussions:

- OCCSs expected not to approach to land area, especially at FDT10 or FDT15, have higher possibility to attain to TS.
- OCCSs located in higher latitudes tend to attain to TS in a shorter time.

Table 4.1 Results of the study (from 2002 to 2006). Numbers in parenthesis indicate the results for OCCSs which were located to the east of 130° E at each base time point.

Base time point (BTP)	Number of OCCSs reached each BTP	Percentage (%) of OCCSs attained NTD and WTD before or at each BTP		Percentage (%) of OCCSs which finally attained to NTD, WTD and TS			Average period (days) from each BTP to FDTS
		NTD	WTD	NTD	WTD	TS	
FDOCS	453 (346)	17	3	46	34	26 (29)	2.3
FDT10	188 (135)	74	30	89	78	61 (67)	1.4
FDT15	112 (83)	96	80	97	95	79 (86)	0.8
FDT20	41 (29)	100	97	100	100	98 (100)	0.4

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