Cloud Grid Information Objective Dvorak Analysis (CLOUD) at the RSMC Tokyo - Typhoon Center

Kenji Kishimoto, Masaru Sasaki and Masashi Kunitsugu
Forecast Division, Forecast Department
Japan Meteorological Agency

Abstract

The Regional Specialized Meteorological Center Tokyo - Typhoon Center has developed objective methods collectively referred to as Cloud Grid Information objective Dvorak analysis (CLOUD) to identify convective cloud areas and analyze TC intensity. These techniques involve the utilization of Cloud Grid Information (CGI) for TCs – an objective cloud product derived using satellite images from MTSAT and Numerical Weather Prediction outputs. The methods will be put into practical operation in 2013, and their approaches to objective intensity analysis and related verification results are presented here.

1. Introduction

The RSMC Tokyo - Typhoon Center (RSMC: Regional Specialized Meteorological Center, referred to here simply as “the Center”) provides ESCAP/WMO Typhoon Committee Members with information on tropical cyclones (TCs) in its area of responsibility. The information provided includes the results of TC satellite image analysis issued in satellite report (SAREP) format. Staff at the Center analyze TCs with full utilization of meteorological data such as those from surface observations (SYNOP, SHIP and BUOY), satellite products from geostationary and polar-orbiting satellites (including scatterometer-derived wind data) and Numerical Weather Prediction (NWP) outputs. The Center’s operational TC analysis starts with early-stage Dvorak analysis (EDA) (Tsuchiya et al. 2001, Kishimoto et al. 2007, Kishimoto 2008) for TCs in the generation stage followed by conventional Dvorak analysis based on Dvorak (1984) for those in the developing or mature stages.

Dvorak analysis involves the analysis of the center position and intensity for TCs. In such analysis, some effect from the subjectivity of individual analysts is inevitable. Although the use of animated satellite images with high frequency and high resolution reduces subjectivity in center position analysis to a certain extent, the results of intensity analysis are still vulnerable to subjectivity, especially in the identification of cloud areas. To address this problem, the Center has developed objective methods for the identification of convective cloud areas and the analysis of TC intensity utilizing Cloud Grid Information (CGI) for TCs – an objective cloud product operationally output by the Center’s Meteorological Satellite Center (MSC) since 2007. The methods for objective intensity analysis, which are collectively referred to as Cloud Grid Information objective Dvorak analysis (CLOUD), will enter operation in 2013. As the manual approach to TC center position analysis still provides greater accuracy than objective methods, conventional center position analysis will be continued and the results will be utilized in CLOUD.

2. Cloud Grid Information objective Dvorak analysis (CLOUD)

2.1 CLOUD analysis procedure

The main analysis procedures of Dvorak (1984) and the Center are shown in Figures 1 and 2, respectively. As the cloud pattern of a system affects the determination of the cloud system center (CSC), staff at the Center first establish the cloud pattern before fixing the CSC location in operation. CSC positional accuracy is determined for utilization in intensity analysis and as a reference for the credibility of CSC data. The Center uses the early-stage Dvorak analysis (EDA) method developed by its own staff (Tsuchiya et al. 2001, Kishimoto et al. 2007, Kishimoto 2008) based on the T1 classification of Dvorak (1984).

Figure 3 shows a flowchart of the CLOUD analysis procedure, including the determination process for three objective intensities (Data T-numbers (DTs), T-numbers and CI numbers) as

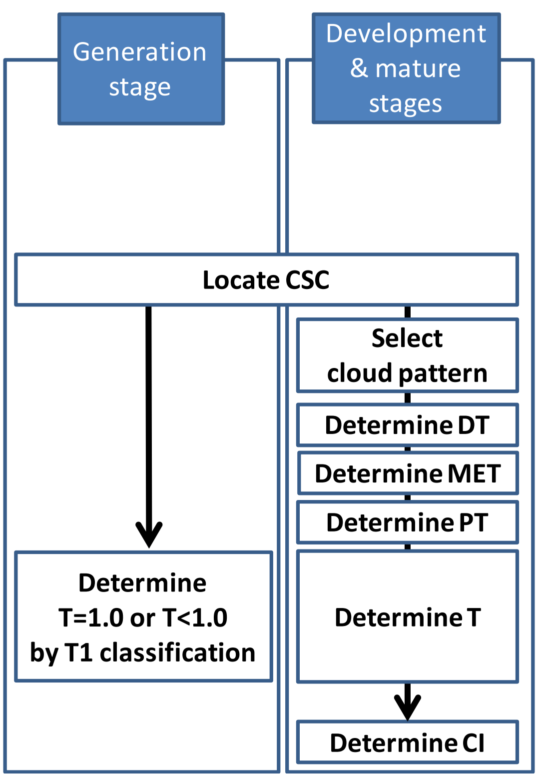

Figure 1 Analysis procedure of Dvorak (1984)

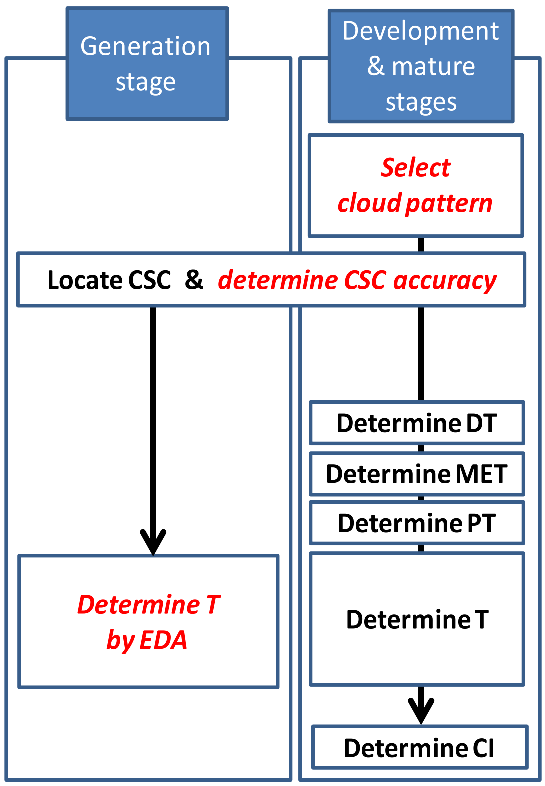

Figure 2 Analysis procedure of JMA

Red italics: JMA's own process

described in Section 2.3. CLOUD provides high interoperability between EDA and Dvorak analysis given only manual input of a cloud pattern and the CSC position along with an indication of accuracy every three or six hours. The technique also allows the determination of Objective CI numbers for TCs in the generation stage (a function not provided in conventional EDA due to a perceived lack of need). The Model Expected T-number (MET) and the Pattern T-number (PT) remain in the hands of analysts due to the subjective nature of such data.

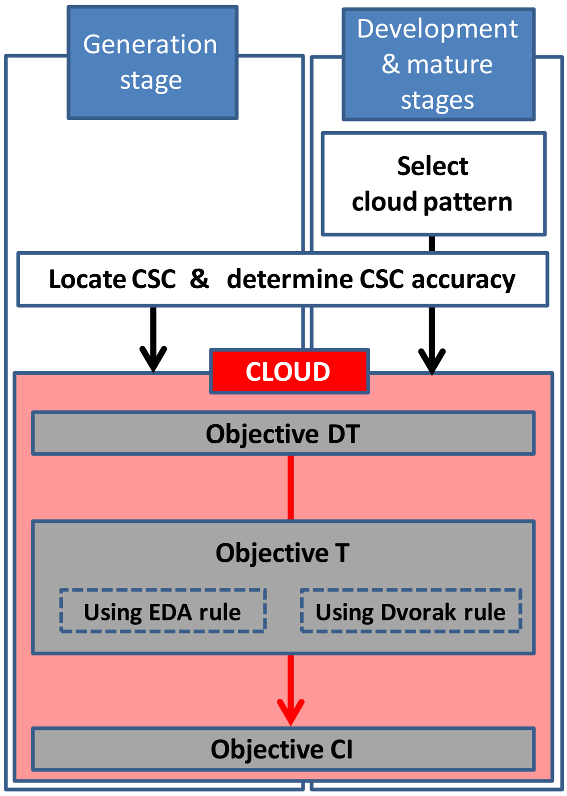

Figure 3 CLOUD analysis procedures

Grey boxes: automatic processes; white box: manual processes

2.2 Preparation for CLOUD

2.2.1 Hourly data input for CLOUD

The temporal variation of Objective DTs is considered to be larger than that of DTs produced by analysts in the conventional method due to the difficulty of performing automatic estimation for the fluctuating convective cloud systems often observed in the TC generation stage, and because of sensitivity to the fixed position of the CSC in the DT determination process. These variations can be eliminated to a certain extent using the previous three-hour average for hourly analysis based on a proposal by Dvorak (1984). In this context, CLOUD can be used to estimate hourly Objective DTs for the latest three-hour period, which are then averaged to give a final Objective DT value.

Hourly Objective DT determination requires information on the hourly cloud pattern, the CSC location and its accuracy as inputs, although these are manually analyzed every three or six hours as part of the Center's operations. The CSC location at the intermediate point between three- or six-hour analysis times is derived by interpolating the analyzed positions, while the cloud pattern and position accuracy for the CSC estimated since previous analyses are set to those of the latest analysis.

2.2.2 Objective determination of cumulonimbus clusters

Determination of cumulonimbus (CB) clusters, which form the main body of a TC, is one of the most important steps in Dvorak analysis. Using CGI, the Center has developed an objective method in which CB clusters within a 3.5-degree latitude of the CSC are defined as potential TC main bodies.

CGI provides grid point values consisting of cloud amounts (total cloud, upper-level cloud and convective cloud), cloud types (cumulonimbus, upper- and mid-level clouds, cumulus, cumulostratus, fog/stratus, overcast and clear sky) and the cloud top height with a spatial resolution of 0.2 × 0.25 degrees in latitude and longitude (http://mscweb.kishou.go.jp/product/product/cgi/index.htm). The information is calculated every 30 minutes based on satellite images and NWP outputs. Cloud

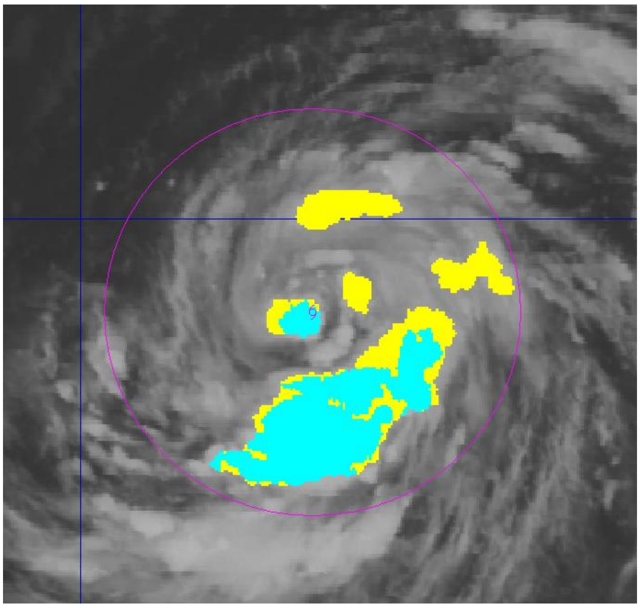

Figure 4 CB clusters objectively extracted using CGI

Yellow and light-blue areas indicate objective CB clusters with cloud-top temperatures of less than -31 and -70°C, respectively.

amounts are derived using Infrared (IR) channels 1, 2 and 3 to avoid variations between daytime and nighttime. In CLOUD, CGI grids occupied 50% or more by CBs are identified as CB grids. In the CB clustering procedure, adjacent CB grids are considered to belong to the same cluster, and clusters with more than 100 CB grids are recognized as CB clusters. Figure 4 shows objective CB clusters extracted using CGI.

2.2.3 Cloud patterns

The four cloud patterns used in CLOUD are the early-stage (E/S), curved band (C/B), eye and embedded center (E/E), and shear (SHR). The E/S pattern is introduced to analysis for TCs in the generation stage. The E/E pattern unifies the eye pattern, the banding eye pattern and the embedded center pattern of the conventional method with integration of the analysis method outlined in Section 2.3.1.3.

2.3 CLOUD analysis method

2.3.1 Objective Data T-numbers

In CLOUD, the intensities of all cloud patterns (E/S, C/B, E/E and SHR) are calculated every hour. The intensity of a cloud pattern as determined by an analyst is adopted as the hourly Objective DT. CLOUD averages hourly Objective DTs for the latest three-hour period to obtain a final Objective DT value. The analysis methods for each cloud pattern are described in Sections 2.3.1.1 to 2.3.1.4.

2.3.1.1 Early-stage (E/S) pattern

In CLOUD, the cloud system's relevant characteristics are identified following the implementation of conventional EDA procedures to classify the intensity of developing convective cloud systems as 1.0 or less. The five characteristics to be identified are as follows:

a. A convective cloud system has persisted for 12 hours or more.
b. The cloud system has a CSC defined within a diameter of 2.5 degrees latitude.
c. The CSC persists for six hours or more.
d. The cloud system has a dense cold (-31°C or less) overcast area within 2 degrees of latitude from the CSC.
e. The overcast has a diameter of more than 1.5 degrees of latitude.

Cloud systems for which all five characteristics are identified are given a T-number of 1.0, those for which four are identified are assigned a T-number of 0.5, and those with fewer than four have a T-number of 0.0.

CLOUD's monitoring range from the CSC to cloud systems is set to 3.5 degrees. This is the maximum sum of the distance of the overcast's position (appearing within 2 degrees of latitude) from the CSC in Characteristic d above, and the diameter of the overcast (more than 1.5 degrees of latitude) in Characteristic e, and is used to identify cloud systems satisfying the condition of Characteristic a, whose persistence time is estimated from the time during which the CB cluster has been within the monitoring range. CSC positional accuracy determined manually is used to identify Characteristic b, the continuation of the CSC is monitored for identification of Characteristic c, the distance from the CB cluster to the CSC is used to identify Characteristic d, and Characteristic e is identified by measuring the CB cluster.

2.3.1.2 Curved band (C/B) pattern

In the C/B pattern, TC intensity is determined from the length of the curved band based on Dvorak (1984). The arc length of the band in CLOUD is measured not from a 10-degree logarithm spiral but from the arc of the band surrounding the CSC (Figure 5). A value of 0.5 is added to the measured intensity for CB clusters with a brightness temperature of -70°C or less.

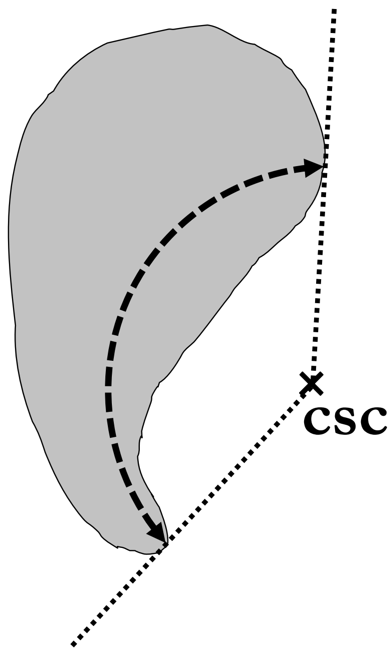

Figure 5 DT measurement for the curved band (C/B) pattern

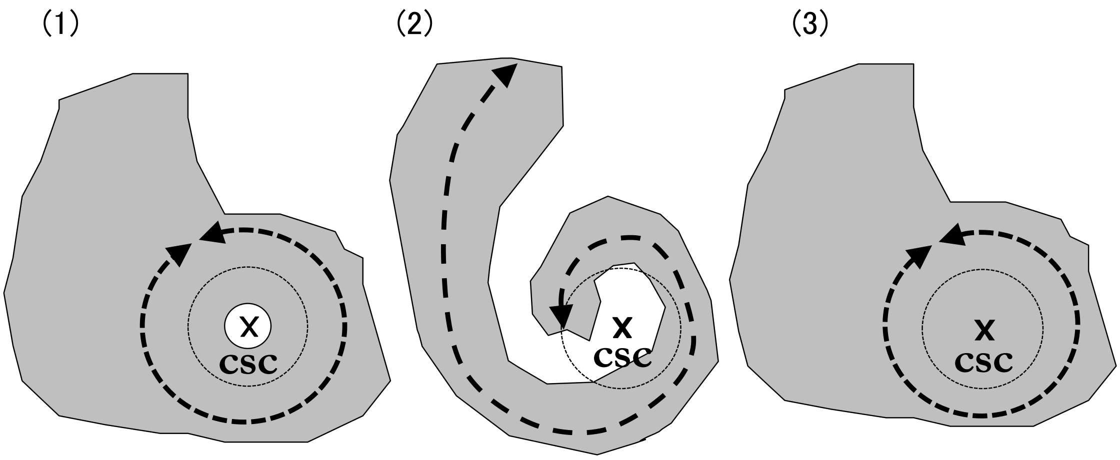

Figure 6 DT measurement for the eye and embedded center (E/E) pattern

(1) Eye (2) Banding eye (3) Embedded center Dotted circles show range of the eye temperature. Dashed curves with arrows show range of the surrounding CB cluster (SUR) temperature.

2.3.1.3 Eye and embedded center (E/E) pattern

In the E/E pattern, CLOUD measures the TC temperature at the eye and the surrounding CB cluster (SUR), and then determines the intensity using these two temperatures based on Dvorak (1984). The highest temperature within a latitude of 0.2 degrees from the CSC is adopted as the eye temperature. The temperature of the coldest ring- or spiral-shaped band with a certain width surrounding the CSC is defined as the SUR temperature. The DT measurement methods for the embedded center pattern and banding-eye pattern are the same as that for the eye pattern (Figure 6). With regard to the embedded center pattern, the eye temperature is considered almost the same as the SUR temperature. This is consistent with the concept of analysis using digital IR data as proposed by Dvorak (1984).

2.3.1.4 Shear (SHR) pattern

For the development stage, CLOUD initially involved the use of the original method for the SHR pattern as proposed by Dvorak (1984), in which the distance from the CSC to a CB cluster is measured (with grids of –31°C or less). The experiment results presented a number of problems relating to the determination of the relationship between the positions of the CSC and the targeted CB cluster. These issues occurred mainly due to inaccurate CSC position fixing at nighttime or intensity overestimation caused by measuring the distance to unexpected and unorganized CBs generated close to the CSC. These issues often led to low priority of the DT in the SHR pattern even in the conventional Dvorak T-number determination process. However, another experiment carried out at the Center showed that the intensity of the C/B pattern with bias correction could be adopted for the SHR pattern. In consideration of these results, the bias-corrected intensity of the C/B pattern is utilized for the SHR pattern.

2.3.2 Objective T-number

The Objective T-number is derived from the Objective DT in consideration of constraints on the time variation of the T-number. The constraints provided by Dvorak (1984) are:

a. T-numbers below 4.0: within 1/2 over 6 hours
b. T-numbers of 4.0 or more: within 1 over 6 hours, 1.5 over 12 hours, 2 over 18 hours, and 2.5 over 24 hours

Conversely, CLOUD provides the following time change constraints:

a. 0.0833 per hour (0.5 over 6 hours) for TCs with an Objective T-number of 3.0 or less.
b. 0.13 per hour (0.78 over 6 hours) for TCs with an Objective T-number of more than 3.0.

The threshold T-number of 3.0 used in CLOUD was devised to address the problem of Objective T-numbers showing a slow-development tendency for rapidly intensifying TCs.

2.3.3 Objective CI number

Objective CI numbers are determined from Objective T-numbers based on the rules of Dvorak (1984) as follows:

a. The CI number is the same as the T-number during the development stages of a tropical cyclone.
b. The CI number is held higher than the T-number while a cyclone is weakening. The CI number is not lowered until the T-number has shown weakening for 12 hours or more. (Hold the CI number 1/2 number higher when the T-number shows a 24 hour decrease of 1/2 number.)
c. When redevelopment occurs, the CI number is not lowered even if the T-number is lower than the CI number. In this case, let the CI number remain the same until the T-number increases to the value of the CI number.

With regard to b, a period of nine hours is adopted as the time for holding the CI number in CLOUD in order to address the problem of Objective T-numbers having a slow weakening tendency.

For TCs making landfall, CLOUD provides Objective CI numbers based on the related rules proposed by Koba et al. (1989). The same rules are also applied to obtain CI numbers for TCs over water with a sea surface temperature below 24°C. For generation-stage TCs determined as having an E/S pattern, the Objective CI number is replaced with the Objective T-number.

3. CLOUD validation

3.1 Statistical verification

3.1.1 Verification range

Verification was performed for experimental CLOUD analysis with cases in which the Center operationally applied EDA and Dvorak analysis over a two-year period from 2011 to 2012. In the verification, CLOUD results were compared with those of conventional analysis (six-hourly T-numbers and CI numbers analyzed at 00, 06, 12 and 18 UTC).

3.1.2 Verification results

The results of Objective T- number verification can be summarized as follows:

1) The mean absolute difference of Objective T-numbers (total: 2,012 cases) compared to those of conventional analysis was 0.36 with a bias of -0.07. As shown in Figure 7, 64 percent of cases exhibited absolute differences within 0.5 and 93 percent within 1.0, while 139 cases (7 percent of the total) showed differences of 1.0 or greater, and 29 (1 percent) showed differences of 1.5

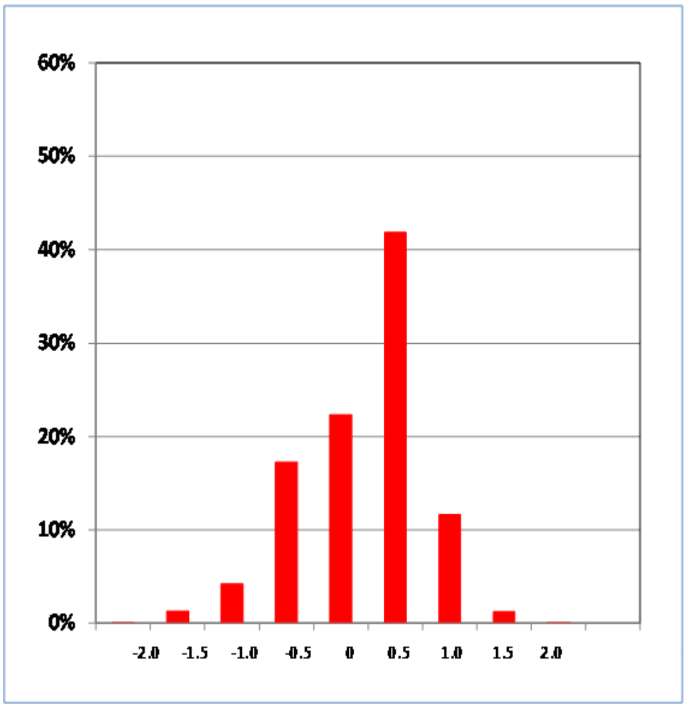

Figure 7 Histogram showing T-number differences between CLOUD and conventional analysis from 2011 to 2012

Vertical axis: percentage Horizontal axis: T-number difference calculated by subtracting conventional analysis from CLOUD values or greater.

2) In the 139 cases with absolute differences of 1.0 or greater, 72 were underestimated because CLOUD could not identify cloud areas as CB clusters. A total of 39 cases had less accurate DTs in the TC weakening stage, and all of these involved the rejection of DTs in the operational T-number determination process (PTs were adopted).

The first result shows that the accuracy of CLOUD's Objective T-numbers is suitable for operational use, and the second one indicates a need for the inclusion of manual processes such as visual checking of objective CB clusters and T-number determination in the TC weakening stage, which could be covered in operational procedures.

The results for Objective CI numbers closely match those for Objective T-numbers, and can be summarized as follows:

1) The mean absolute difference of Objective CI numbers (total: 2,012 cases) compared to those of conventional analysis was 0.36 with a bias of 0.00. A total of 65 percent of cases exhibited absolute differences within 0.5 and 94 percent within 1.0, while 127 cases (6 percent of the total) showed differences of 1.0 or greater, and 18 (1 percent) showed differences of 1.5 or

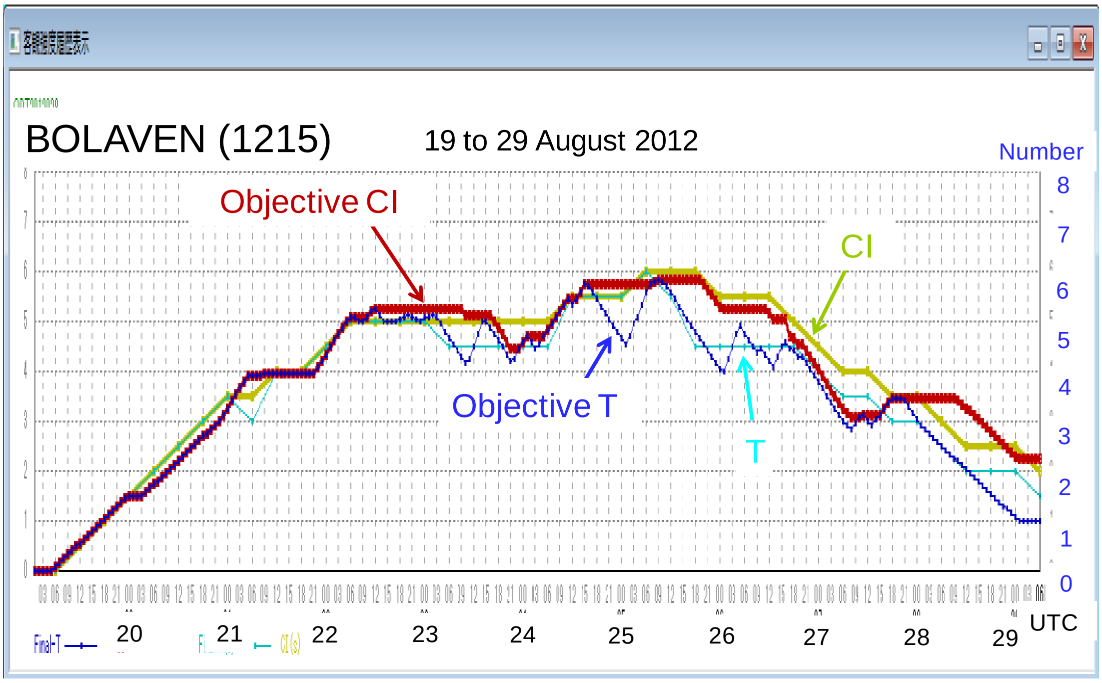

Figure 8 Sample of comparison between the results of CLOUD and those of conventional analysis for TY Bolaven (1215)

Red and dark blue: Objective CI numbers and Objective T-numbers with CLOUD Light green and light blue: CI numbers and T-numbers with conventional analysis greater.

2) In the 127 cases with absolute differences of 1.0 or greater, 40 were underestimated because CLOUD could not identify cloud areas as CB clusters. A total of 63 cases had less accurate DTs in the TC weakening stage, and all of these involved the rejection of DTs in the operational T-number determination process.

An example of CLOUD analysis for TY Bolaven (1215) compared to conventional analysis is shown in Figure 8.

3.2 Verification utilizing aircraft observation

3.2.1 Verification range

CLOUD verification based on data from aircraft observation conducted during field experiments of ITOP in 2010 for TY Fanapi (1011), TY Malakas (1012) and TY Megi (1013) was carried out, and the results from the conventional method (with CI number from six-hourly best-track analysis) and those from CLOUD given the positions of best-track data were compared. The values of central pressure at the analysis time close to the aircraft observation time were verified and compared with the best-track CI number results. Central pressure was converted from both CI numbers based on a table developed by Koba et al. (1991).

3.2.2 Verification results

The results from 31 cases (Table 1) show that the maximum differences in central pressure derived from the best-track CI number appeared in the two cases of 12 hPa plus 986 and 990 hPa from aircraft observations. Those from CLOUD were also observed in the two cases of 17 hPa plus 895 and 913 hPa from aircraft observations. The mean error for the best-track CI number was 5 hPa, and that for CLOUD was 7 hPa. These results highlight the potential validity of the CLOUD approach.

4. Introduction of CLOUD into operational procedure

The Center plans to introduce CLOUD into operational Dvorak analysis process in 2013 (Figure 9). The new procedure will involve a combination of objective and manual processes.

The introduction of CLOUD will simplify the Center's operational analysis procedures from TC generation to the mature stage. In the new procedure, the cloud pattern and the CSC position (and its accuracy) are first defined for the TC in question. In the TC generation stage, E/S is always selected as the cloud pattern. These inputs lead to the Objective DT, T- and CI numbers automatically calculated by CLOUD. The Objective T-number rather than the Objective DT will be adopted as the final DT in operation for its higher accuracy. The final T-number is selected from among the final DT, the PT and the MET both of which are determined by an analyst. In the TC generation stage, the final DT undergoing a manual check and necessary modification is adopted as the final T-number.

The final CI number is automatically determined using the conventional method. As the final step, TC intensities (maximum wind speed and central pressure values) are determined by the final CI number and other observation data using the CLOUD Objective CI number as reference.

The Center has developed a system called SATAID (Satellite Animation and Interactive Diagnosis) that allows analysts to monitor and analyze satellite images not only for daily weather analysis but also for Dvorak and EDA analysis. The CLOUD algorithm has been integrated into this system, and a sample of the prototype is shown in Figure 10.

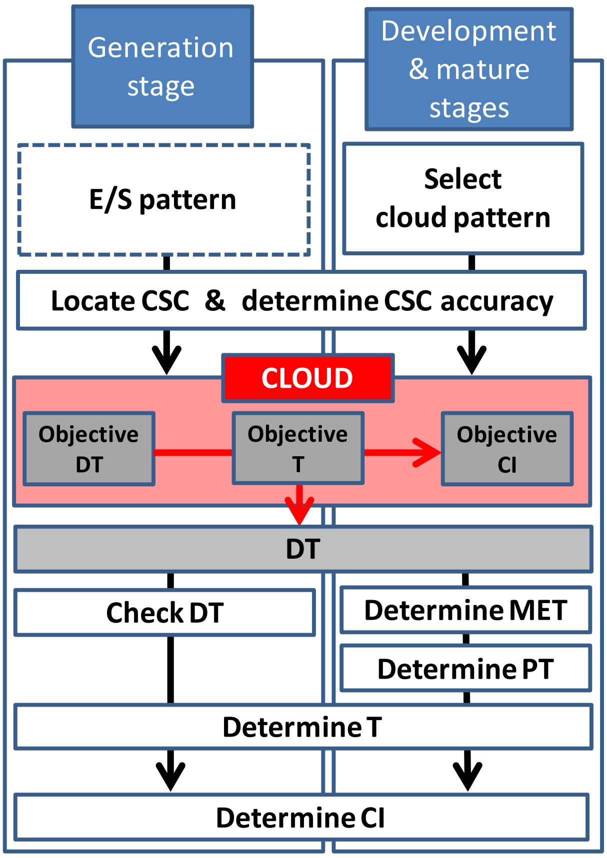

Figure 9 Planned JMA analysis procedure

Grey boxes: automatic processes; white boxes: manual processes

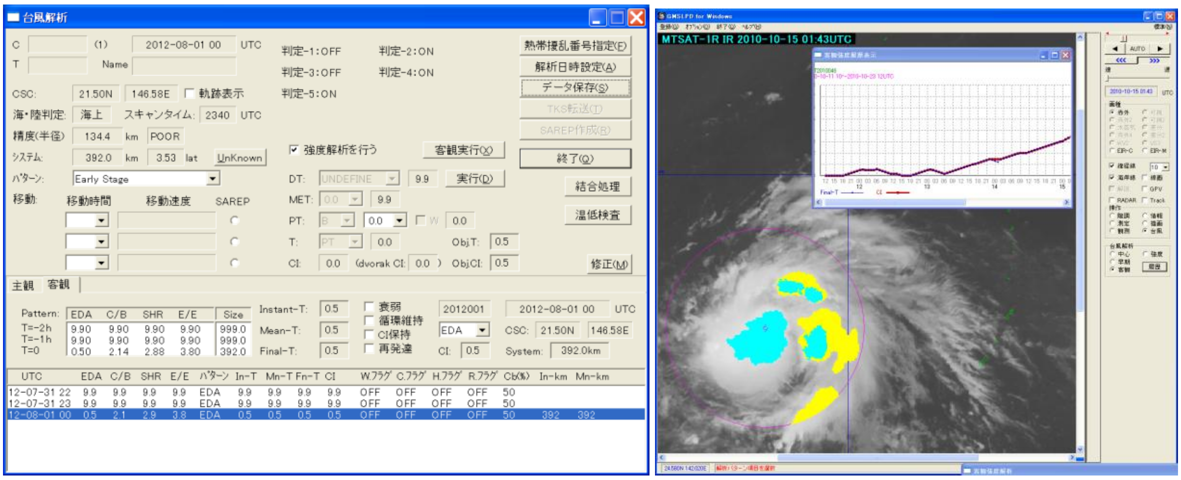

Figure 10　CLOUD prototype sample in SATAID

5. Discussion

The results of verification for the CLOUD system developed by the Center indicate the feasibility of its introduction for use in operational procedures. Analyst feedback from evaluation of the trial phase will be reflected for further improvement of the system before its introduction into actual operation.

Table 1 CI numbers and central pressure (CP) values for CLOUD and best-track, and CP values for aircraft observations conducted during ITOP in 2010 for TY Fanapi, TY Malakas and TY Megi

Observation time (UTC)	Aircraft CP (hPa)	Best-track CI number	Best-track CP (hPa)	Difference (hPa)	CLOUD CI number	CLOUD CP (hPa)	Difference (hPa)
0000, 16 Sep.	984	3.5	981	3	3.3	983	1
0300, 16 Sep.	979	3.5	981	2	3.3	983	4
0100, 17 Sep.	970	4.5	965	5	4.7	962	8
0300, 17 Sep.	968	4.5	965	3	4.8	961	7
2300, 17 Sep.	944	5.5	947	3	5.5	946	2
0000, 18 Sep.	941	5.5	947	6	5.7	944	3
0100, 18 Sep.	940	5.5	947	7	5.8	941	1
2100, 22 Sep.	989	3.0	987	2	2.8	990	1
2200, 22 Sep.	987	3.5	981	6	2.9	989	2
0000, 23 Sep.	985	3.5	981	4	3.0	987	2
1600, 23 Sep.	974	4.5	965	9	4.0	974	0
1800, 23 Sep.	973	4.5	965	8	4.2	970	3
2000, 23 Sep.	972	4.5	965	7	4.5	966	6
2100, 23 Sep.	972	4.5	965	7	4.6	963	9
2200, 23 Sep.	971	4.5	965	6	4.8	961	10
1700, 24 Sep.	948	5.5	947	1	5.5	948	0
1900, 24 Sep.	947	5.5	947	0	5.5	948	1
0100, 14 Oct.	999	1.5	1002	3	2.0	998	1
0200, 14 Oct.	990	1.5	1002	12	2.0	998	8
0400, 14 Oct.	986	2.0	998	12	2.2	996	10
2000, 14 Oct.	980	3.0	987	7	2.9	988	8
2100, 14 Oct.	980	3.5	981	1	3.0	987	7
2300, 14 Oct.	979	3.5	981	2	3.2	985	6
0200, 16 Oct.	967	5.0	957	10	4.9	958	9
0400, 16 Oct.	963	5.0	957	6	4.9	958	5
2200, 16 Oct.	913	7.0	914	1	6.3	930	17
0000, 17 Oct.	908	7.0	914	6	6.6	924	16
0100, 17 Oct.	909	7.0	914	5	6.7	921	12
1100, 17 Oct.	895	7.5	901	6	7.1	912	17
1200, 17 Oct.	893	7.5	901	8	7.2	909	16
1300, 17 Oct.	890	7.5	901	11	7.3	906	16
Ave.				5			7

References

Dvorak V. F., 1984: Tropical cyclone intensity analysis using satellite data. NOAA Tech. Rep. 11.

Kishimoto K., T. Nishigaki, S. Nishimura and Y. Terasaka, 2007: 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, RSMC Tokyo - Typhoon Center Technical Review No. 9, 19 – 32.

Kishimoto K., 2008: Revision of JMA's Early Stage Dvorak Analysis and Its Use to Analyze Tropical Cyclones in the Early Developing Stage, RSMC Tokyo - Typhoon Center Technical Review No. 10, 1 – 12.

Koba, H., S. Osano, T. Hagiwara, S. Akashi, and T. Kikuchi, 1989: Determination of the intensity of typhoons passing over the Philippines (in Japanese). J. Meteor. Res., 41, 157 – 162.

Koba H., T. Hagiwara, S. Osano and S. Akashi, 1991: Relationships between CI Number and Minimum Sea Level Pressure/Maximum Wind Speed of Tropical Cyclones, Geophysical Magazine, Vol. 44, No. 1, 15 – 25.

Tsuchiya, A., Mikawa, T. and Kikuchi, A., 2001: Method of Distinguishing Between Early Stage Cloud Systems that Develop into Tropical Storms and Ones that Do Not, Geophysical Magazine Series 2, Vol. 4, Nos. 1 – 4, 49 – 59.