CLOUD TRACK WIND MEASUREMENT IN JAPAN

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1. INTRODUCTION

Mid-1970's, NESDIS/NOAA began their operational wind derivation, and subsequently MSC/JMA and ESOC/EUMETSAT also started operational wind derivation in pre-First GARP Global Experiment (FGGE) year (1978) and at this time the global Cloud Motion Wind (CMW) derivation system was established.
As well known, five geostationary meteorological satellites have been nominally operated above the equator since FGGE period. But actually 4 to 3 satellites have been in operation after FGGE period. The CMW are operationally derived from those satellite images by ESOC/EUMETSAT,NESDIS/NOAA and MSC/JMA.

1.1 Images and their registration

In order to estimate the Cloud Motion Wind,either infrared(IR) or visible(VIS) satellite images usually taken at 30-minute interval are used for target cloud selection and tracking, and IR, VIS and/or water vapor(WV) channel's images for the estimation of target cloud height and wind representative height.
For correct tracking of the target cloud, the relationship between target cloud location on the image and the location on the earth must be accurately determined. For this purpose, the orbital and attitude data of the satellite and some other imaging information like scan geometry are used to calculate the relationship between them. The error (absolute error) is generally 10 km or more on the earth surface, but the absolute error of image registration is not so serious because it vanishes in the calculation of vector from two time-sequential images if the images are relatively well registered. In order

to increase the accuracy, a set of landmarks is used to adjust the image to earth location. In addition to this method, the MSC/JMA redetermine the attitude of the satellite using the landmark locations determined on five VIS images a day, and then predict the attitude for 4 days on. Furthermore, when each image is ingested the earthedge is extracted from the IR full disc image and then earth location in the image is finely tuned. The predicted attitude and orbital data, scan geometry of the satellite and fine-tuned earth location are used for wind vector calculation.

1.2 Target cloud selection and tracking

There are generally two types of target cloud selection and tracking procedures; namely,manual and automatic procedures. In the automatic procedure, the cloud height information is used for selection of suitable target to be tracked. The tracking is performed by the pattern matching technique. In the manual procedure, on the other hand, an operator selects and tracks suitable targets on a CRT on which animated movie-loop is electronically displayed.

1.3 Height assignment

The satellite wind is assigned to the most probable altitude which is estimated from (a) IR brightness temperature (TBB), (b) TBB and WV channel (6μm) observation, (c) TBB and VIS brightness, (d) statistical wind representative height based on a previous investigation, or (e) subjective wind representative height.

1.4 Quality control

It is necessary to remove unrepresentative winds among the resultant vectors. Some vectors are removed or flagged in the automatical procedure, and some in the manual procedure by a skillful analyst.

1.5 Delivery and archiving

Final vectors are coded into WMO formats (SATOB) for the teletype transmission to worldwide users through the GTS.

1.6 Japanese cloud wind estimation system

Japan has deriving cloud motion winds by the Cloud Wind Estimation System (CWSE) at the MSC since April 1978,and many kind of developement /improvement were done.

Since January ,1989,cloud motion winds are derived four times per day,00UT,0&UT,12UT and 18UT at the Meteorological Satellite Center (MSC).
There are generally two types of target cloud selection and tracking processes : namely, manual and automatic processes. In the automatical process, the cloud height information is used for selection of suitable target cloud to be tracked. The tracking is performed by a pattern matching technique. In the manual process, an operator selects and tracks suitable targets on an animated movie loop.
The general process flow of MSC Cloud Winds Estimation System (CWES) is shown in Fig.1. Two types of cloud motion winds are available from the CWES. One is cumulus level or low-level cloud motion wind which is derived through automatical process, and another is cirrus level or high-level cloud motion wind which is derived through combined processes: automatical process and man-machine interactive process. Both types of winds are assigned to certain levels and quality-checked manually and automatically. The extracted winds are coded into WMO formats (SATOB) and transmitted to the Forecast Department of JMA via ADESS. These winds are used as the initial data for numerical weather prediction and also used as the basic data for typhoon analysis, and are transmitted to world-wide users via GTS.
In the following sections, the procedures of the CWES are described.

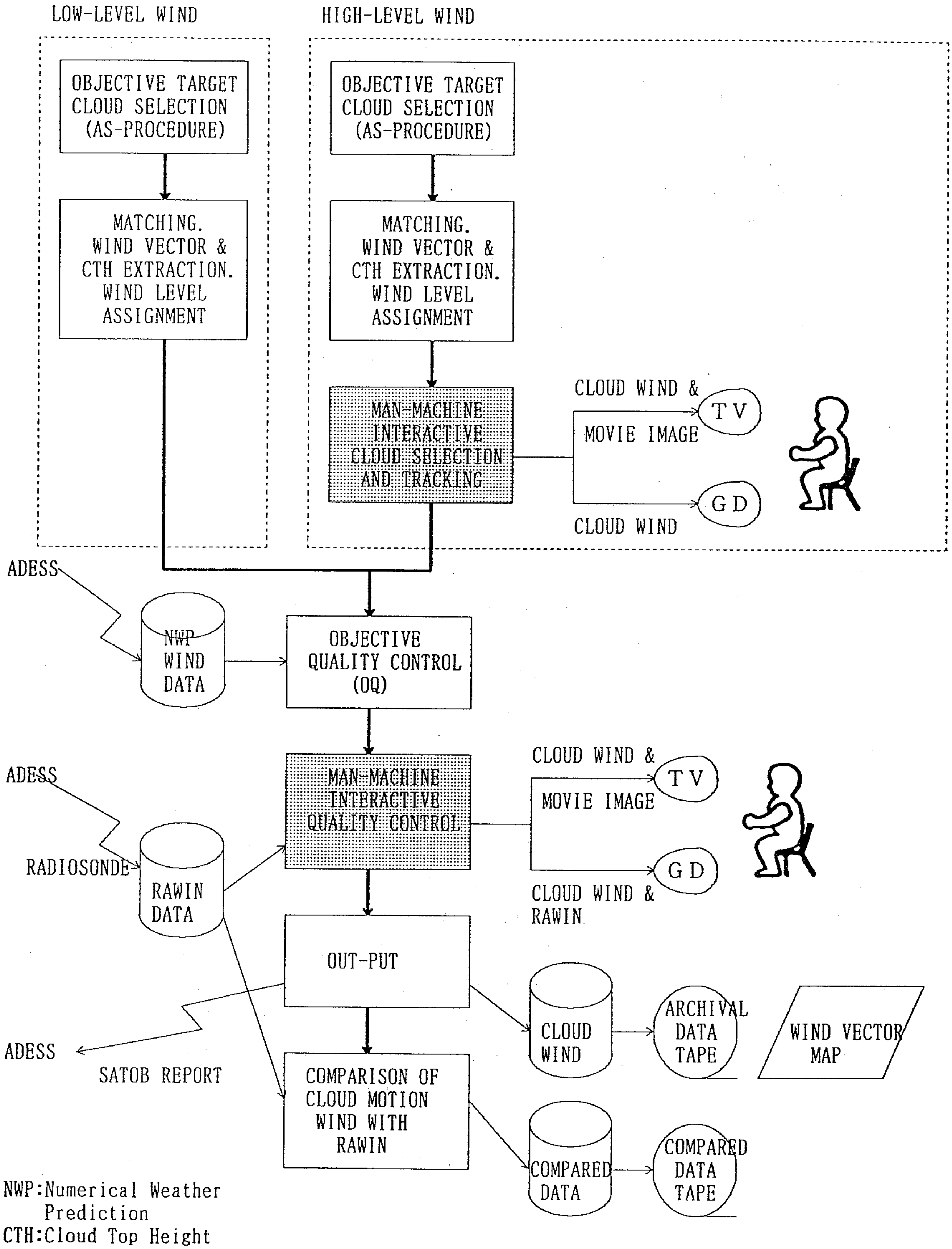


Fig. 1 Processing flow of Cloud Wind Estimation

2. LOW-LEVEL WIND DERIVATION

For low-level wind derivation, cumulus clouds such as trade cumulus are tracked.

2.1 Target Cloud Selection

There are two types of processes for low-level target cloud selection : automatical process and man-machine interactive process. Automatical process is currently used operationally. Man-machine interactive process is described in section 3.

Automatic cloud selection (AS) procedure is a procedure of objective (Automatic) target cloud Selection based on an analysis of the histogram on the infrared brightness temperatures.

a. Grid points and observation area

The candidate points for automatic target selection are provided at grid points with certain intervals of latitude and longitude as shown in Fig.2.

Latitude and longitude (ϕ_0, λ_0) of northwest corner of the observation area, spacings ($\Delta\phi, \Delta\lambda$) and numbers of grid points (N_ϕ , N_λ) are given as present values. Each candidate grid point is put into the following screening steps to get final AS point to be tracked in the following matching procedure.

b. Screening Step 1 : Ocean/land discrimination

When the land area ratio to the box area (1°latitude/longitude) centered at a grid point is greater than a certain preset threshold value, the very grid point is rejected from the candidates of the AS point. The contamination of land pattern like coastal line, river, mountain etc.causes the mis-tracking of the target clouds. In order to eliminate such mis-tracking, this screening step is needed. Currently 0 % is given as the preset threshold value in routine operation, that is , land area is excluded from the observation area.

c. Screening Step 2 : Zenith angle of the satellite

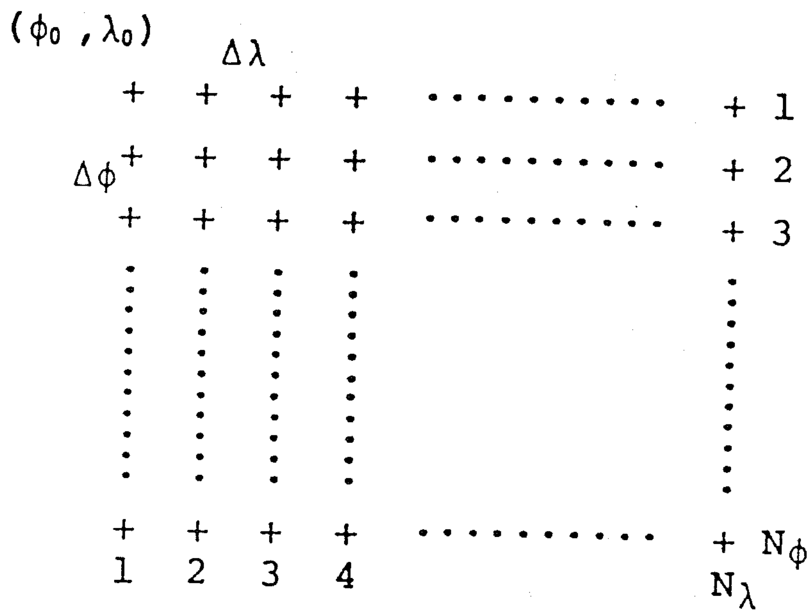


Fig. 2 Grid points for AS procedure.

and the sun

When the following conditions on the zenith angle of the satellite (t) and the sun (s) are satisfied, the candidate of AS point passes through this screening step.

$$t < t_0 \ , \quad s < s_0 \qquad (1)$$

where t_0 and s_0 are given as preset values.
The second condition on the zenith angle of the sun is only applied for visible image tracking.

d. Screening Step 3 : Histogram analysis

This is the final screening step based on histogram analysis on infrared brightness temperature.
From a small area (N_L lines x N_P pixels) centered at AS grid point passing through the previous screening steps, a histogram of infrared brightness temperature is generated and the feature of the histogram is parameterized as shown in Fig.3. The parameters are compared with preset threshold values, and in case the conditions are satisfied, the AS grid point is regarded as the final AS point to be tracked in the following matching procedure.
The terms between parentheses in Fig.3 are preset values. Among them, TLM_{high} ,TLM_{low} ,TLM_{amt} are threshold values, X and Y are values for the calculation of parameters to be compared with the threshold values, and a preset value, Z, is used for the modification of the threshold value, TLM_{low},into TBB_{low} . Besides there are four more threshold values. T_1 and T_2 give the threshold value for the limitation of thickness of target clouds. C_{min} and C_{max} give the threshold value for the limitation of cloud amount of target cloud area. The meanings of parameters and the values currently used for a routine operation are shown in Table 1.

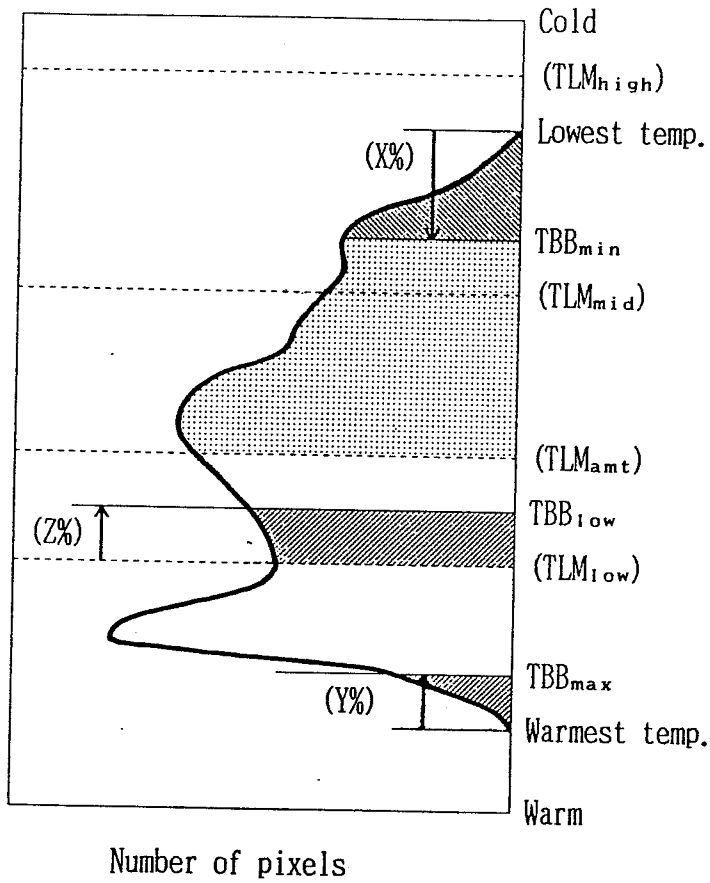


Fig. 3 View of the histogram on infra-red brightness temperatures for automatic cloud selection.

Table 1 Parameter for histogram analysis to select target cloud automatically.

(a) Parameters determined from the feature of histogram on infra-red brightness.

Parameter	Definition	Comment
TBB_{min}	Temperature at X% of total frequencies from the lowest temperature.	X, Y and Z are given as preset values, i.e. initial parameters.
TBB_{max}	Temperature at Y% of total frequencies from the highest temperature.	
TBB_{low}	Temperature at Z% of total frequencies from TLM_{low} toward temperature.	
C_{amt}	Cloud amount which is percentage of cloud higher than TLM_{amt}.	

(b) Threshold values and values for calculation of the parameters shown in (a).

Parameter	Meaning	Low-level	High-level
PLM_{Low}	Pressure at lower limit.	950mb	450mb/500mb
TLM_{Low}	Temperature converted from PLM_{Low} by vertical temperature profile (VTP) or clear sky radiance data.	—	—
PLM_{mid}	Boundary pressure level between mid-level and low-level.	—	—
TLM_{mid}	Temperature converted from PLM_{mid} by VTP.	—	—
PLM_{high}	Pressure at upper limit.	600mb/650mb	150mb/Trop.
TLM_{high}	Temperature converted from PLM_{high} by VTP.	—	—
PLM_{amt}	Pressure at lower limit for calculating cloud amount	850mb	450mb/500mb
TLM_{amt}	Temperature converted from PLM_{amt} by VTP.	—	—
X	Percentage of total number of pixels for determination of TBB_{min}, TBB_{max} and TBB_{low} each ($X + Y \leqq 100\%$).	0.1%	
Y		99.9%	
Z		1.0%	
T_1	Limitation of thickness of the target cloud layer ($0.0\ ℃ < T_1 < T_2$).	2.0℃	2.0℃
T_2		35.0℃	60.0℃
C_{min}	Limitation of cloud amount of the target cloud layer ($0.0\% \leqq C_{min} \leqq C_{max} \leqq 100.0\%$).	1.0%	5.0%
C_{max}		100.0%	99.0%

(c) Other parameters.

Parameter	Meaning	Value
$N_L \times N_P$	Histogram area (lines × pixels)	32 × 32
t_0	Threshold parameter of zenith angle of satellite	60°
s_0	Threshold parameter of zenith angle of sun	85°

The following conditions are applied to each AS points.

Condition 1 : The limitation of the target cloud temperature range.

$$TBB_{min} < TLM_{low} \qquad (2)$$

$$TBB_{max} > TLM_{high} \qquad (3)$$

Condition 2 : The limitation of thickness of the target cloud layer.

$$T_1 < TBB_{low} - TBB_{min} < T_2 \qquad (4)$$

Condition 3 : Classification of the target cloud layer. (This condition is not for screening but for the classification.)

The target cloud is classified to ;

$$\text{low-level (Cu), when} \quad \sum_{i=TBB_{min}}^{TBB_{low}} i \times f_i \Bigg/ \sum_{i=TBB_{min}}^{TBB_{low}} f_i \geqq TLM_{mid} \qquad (5)$$

$$\text{mid-level (As), when} \quad \sum_{i=TBB_{min}}^{TBB_{low}} i \times f_i \Bigg/ \sum_{i=TBB_{min}}^{TBB_{low}} f_i < TLM_{mid} \qquad (6)$$

where f_i is a pixel frequency specified by the temperature level 'i'.

Condition 4 : The limitation of cloud amount of the target cloud area.

$$C_{min} \leqq C_{amt} \leqq C_{max} \tag{7}$$

Currently 800 is routinely give as the initial number of AS point. The observational area and spacings of AS grid points are fixed. However, the number of final AS points changes irregularly because the situation of cloud distribution varies from one observation to another. If the AS screening procedures was applied to the grid points in a fixed order, for example, from north to south, it might be possible that no AS point is selected in some area. To avoid this, histogram analysis is applied in random order to the grid points in the observational area.

Thus the final AS points are selected and then sent to the following matching step.

2.2 Tracking (Matching)

The corresponding cloud pattern of the same target cloud selected in the AS procedure is searched on another image taken 30 minutes before or later using cross-correlation technique. On the first picture, digital image data of 32 pixels by 32 lines, centered at a selected point are used as template data. On the second picture taken 30 minutes before or later, image data of 64 by 64 are used as search area data. The correlation values between the brightnesses of the template area and the search area are calculated for each lag point and a cross-correlation coefficient matrix is obtained.

The correlation matrix is given by :

$$C(p,q)=\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}(T(i,j)-\overline{T})(S(i+p,j+q)-\overline{S}(p,q))}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N}(T(i,j)-\overline{T})^2}\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N}(S(i+p,j+q)-\overline{S}(p,q))^2}} \quad (8)$$

where $T(i,j)$ Brightness level of template data $i,j=1,2,3,\cdots,N$

$S(i+p,j+p)$ Brightness level of search area data $i,j=1,2,3,\cdots,N$

$$p,q=-\frac{N-M}{2}, -\frac{N-M}{2}+1,\cdots,\frac{N-M}{2}-1,\frac{N-M}{2}$$

(p,q) is lag-position on matching surface

$$T=\frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}T(i,j)$$

$$S(p,q)=\frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}S(i+p,j+q).$$

The biggest value of the correlation coefficients is adopted as the best matched position. Schematic relationship between the template area and the search area used for calculating cross-correlation matrix is shown in Fig.4. The cross-correlation coefficient matrix depicted in three dimensional feature is shown in Fig.5. It is called a matching surface and used for quality control on matching process, as described in Section 4.

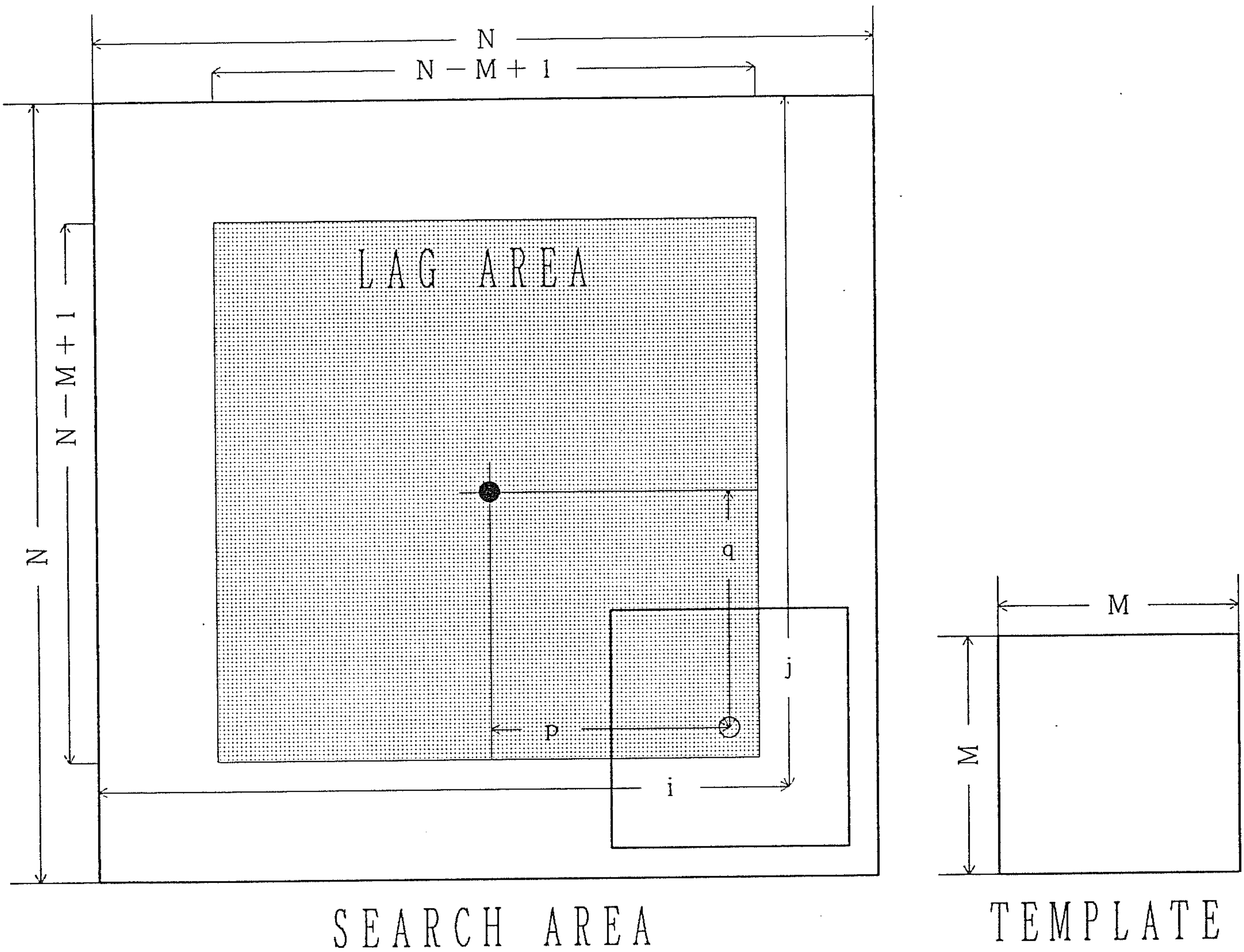


Fig. 4 Schematic relationship between template and search area.

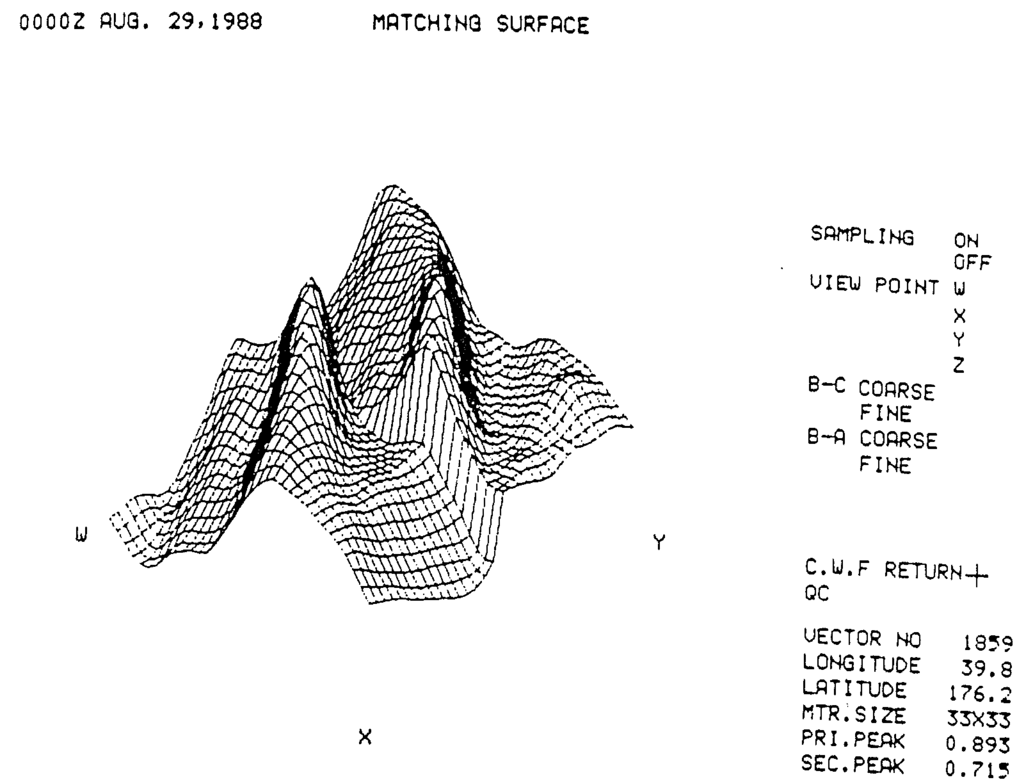


Fig. 5 Three dimensional display of cross-correlation matrix (matching surface).

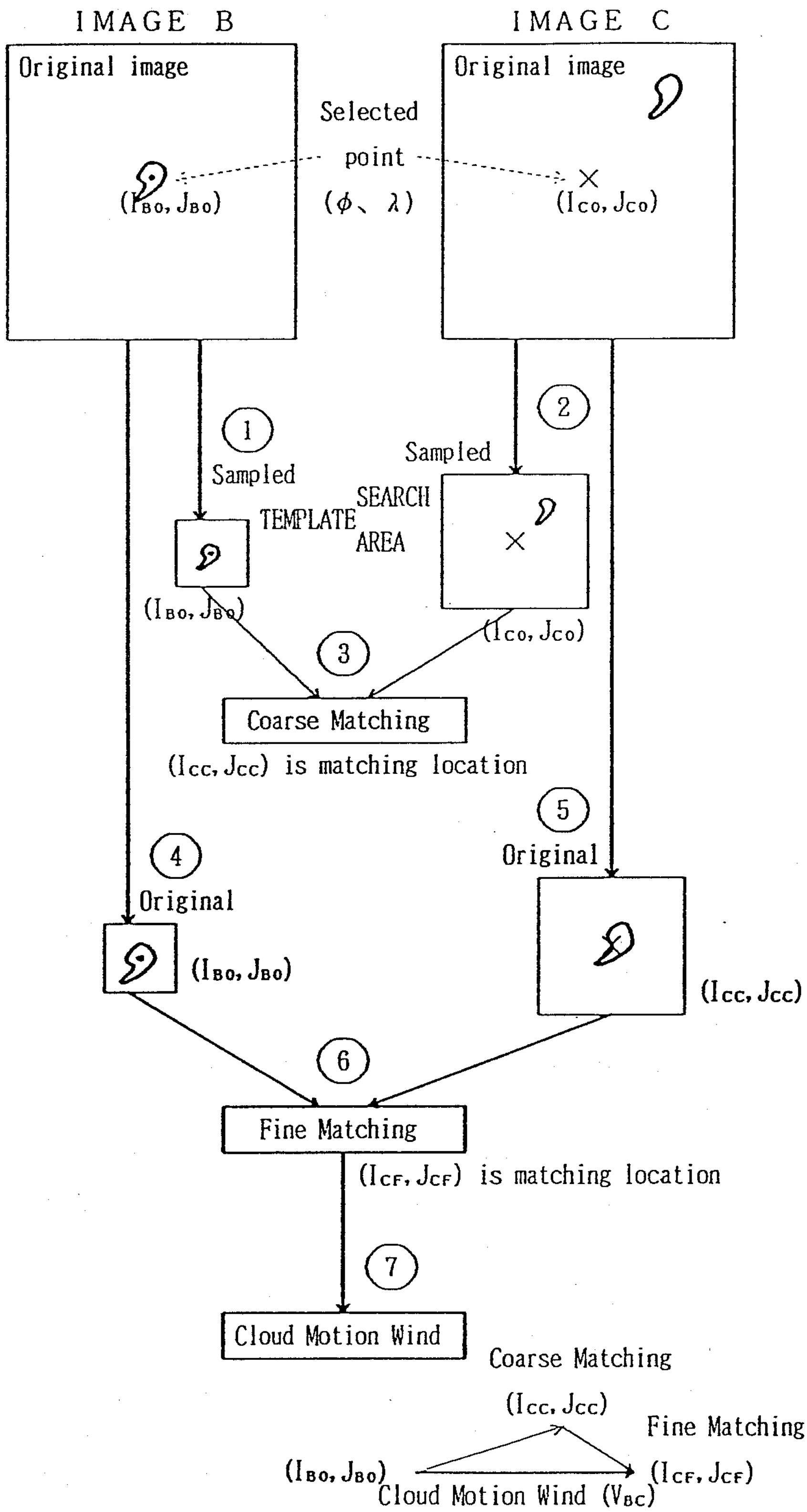
Double matching method, shown in Fig.6, is adopted in tracking target clouds. At first, on spatially sampled images the AS target cloud is tracked and a coarse vector of the displacement is derived, which is called coarse matching. Next, on original spatial resolution images, a correction vector is derived for fine tuning of the displacement in similar procedure of coarse matching, which is called fine matching. Sum of the coarse vector and the correction vector is a resultant cloud displacement or motion. The sampling rates in the coarse matching are given as preset values.

Three images are usually used for tracking the AS targets. These images are called images A,B and C taken at about 30 minutes intervals. Target clouds are selected on the image B by AS procedure and the double matching method is applied to derive target cloud displacement between images B and C. The inverse displacement vector from image B to C is used as a coarse vector between images B and A. Only fine matching is performed between images B and A. Consequently we get two time-sequential vectors, V_{AB} and V_{BC} ,from a target cloud selected on image B.

Matching scheme mentioned above is used for routine operation. In case of lacking one of these images, remaining two images are used for tracking.

The pixels of the image data used for matching process are at discrete positions, which therefore causes truncation error to the cloud motion winds. In order to eliminate the truncation error, the matching location is interpolated among the discrete picture elements around that of maximum correlation value. The top value on the matching surface is found by interpolating on the direction of pixel and line respectively, and the best-match location is decided.

The resultant vectors on the image coordinate system calculated in the previous procedure are transformed into wind vectors on the earth coordinate system on the basis of the predicted satellite attitude and orbital data. The vector between the images B and C (V_{BC}) is regarded as the final wind, and the



(i) : Number of processing sequence to derive wind (V_{BC}).

Fig. 6 Double Matching Scheme between image B and image C.

V_{AB} is used for quality control of the wind vector.

2.3 Height Assignment

Three cloud top heights (CTHs) are derived from three infrared images A,B and C for each wind data. The lowest black body temperature, TBB is extracted from an infrared image centered at a selected point in target cloud selection or at a matching point determined in the matching procedure. T_{BB} is converted into a temperature of cloud top, T_C ,taking account of the effect of atmospheric attenuation. Then ,T_C is transformed into CTH both in pressure level and in geo-potential height, using vertical temperature profiles obtained from the 12-hour forecasts of JMA numerical weather prediction.
These height information is used for quality control of the cloud motion winds, and for representative height assignment of the wind vector described below.
The fixed wind representative height, 850hp, is assigned to all resultant winds from low-level target cloud with the CTH lower than the limitation height. This height is either 600 hp or 650 hp which varies seasonally and regionally as shown in Table 2. Those fixed wind representative height and the limitation heights were determined on the basis of statistical level-of-best-fit based on the comparison between cloud motion wind and radiosonde wind.

3. HIGH-LEVEL WIND DERIVATION

For high-level wind derivation, cirrus clouds are tracked. High-level wind is also derived in land area in addition to sea area.

3.1 Target Cloud Selection and Tracking

Two types of processes for high-level target cloud selection are available : automatical process and man-machine interactive process. Currently both processes are used operationally.

Table 2 Limitation height (PLM_{high}) of cumulus clouds to be tracked for low-level wind derivation

SEASON	WINTER	SPRING	SUMMER	AUTUMN
NORTHERN HEMISPHERE	600 mb	650	650	650
EQ				
SOUTHERN HEMISPHERE	600	600	600	600
SEASON	SUMMER	AUTUMN	WINTER	SPRING
	DEC 14/15	MAR 14/15	JUNE 14/15	SEP 14/15 — DEC 14

(1) Automatical process

Automatical process is almost the same method as the process used in the low-level cloud motion calculation.

a. Grid points and observational area

The candidate points for automatic target cloud selection are provided by the same way as that in low-level wind.

b. Screening Step 1 : Ocean/land discrimination

This screening step is not used for the high-level wind. Because most of the infrared brightness temperatures of high-level target cloud is considerably different from that of the land area, the contamination of land pattern causes less mis-tracking of the target clouds.

c. Screening Step 2 : Zenith angle of the satellite and the sun

This screening step is used in the same way as that in low-level.

d. Screening Step 3 : Histogram analysis

The final screening step is performed by the same way as that in low level. However, the values of parameters used on the histogram analysis in high-level are different in three latitudinal zones : equatorial zone, polarward from 25 degrees of the north latitude, and that of the south latitude. The values of parameters which is currently used operationally for the high-level target cloud are shown in table 1.
It is difficult to determine correct temperature of cirrus cloud due to ambiguity of the emissivity that range from less than 0.1 up to near unity. In a histogram analysis of the infrared brightness temperatures,dense cirrus can be selected as a high-level target cloud, but thin cirrus which has small emissivity cannot always be selected. Because thin cirrus is often a good target to be tracked, the man-machine interactive process is necessary to select and track the thin cirrus as a

target cloud.

Considering sufficient time for the man-machine interactive process, the initial number of AS points given routinely in high-level wind calculation is 500. The AS screening procedures in high-level wind calculation is applied in random order to the grid points. The final AS points are sent to the matching step which is the same method as that in low-level, and the wind vectors are calculated.

(2)<u>Man-machine interactive process</u>

The man-machine interactive process is used to derive the high-level cloud motion wind in addition to the winds which are calculated automatically. The animation of three time-sequential images is displayed on CRT-display which is the high resolution color display screen (1024x1024 dots) of the Image Processing Console (IPC). The man-machine interactive target cloud selection is performed by an operator on the CRT-display.

Routinely a suitable target is selected on the second image (Image B) by a stylus-pen. The target is tracked automatically in three time-sequential images by a cross-correlation technique which is the same method as the automatical process. The resultant vector is transformed into wind vector with earth coordinates using predicted satellite orbital and attitude data. The calculated vector is immediately displayed on the CRT-display on which the animation of three time-sequential images are superimposed, and is viewed by the operator. The vector between the images B and C (V_{BC}) is regarded as the final wind. This tracking method is called MM-1 method.

Another tracking method is called MM-2 method, in which the manual tracked points are used for cloud motion calculation. Usually the starting point of the target cloud is selected on the first image (Image A) by pointing on the target and the ending point on the third image (Image C). Locations of the starting and the ending points are transformed into winds in earth coordinates using the satellite navigation data.

3.2 Height Assignment

Wind representative heights shown in the Table 3 are assigned to the resultant cloud motion winds. Those representative heights were determined on the basis of statistical level-of-best-fit between cloud motion winds and radiosonde winds.

The statistical wind representative heights are assigned cirrus tracked winds. Also the climatological tropopause levels are assigned to those winds.

4. QUALITY CONTROL

The CWES has three stages of quality control. The first stage is the automatic assessment on matching surfaces, wind velocities, cloud top heights and missing lines (line drops).

The second stage consists of horizontal consistency check, vertical shear check and comparison with numerical weather prediction winds. This stage is called objective quality control (OQ)procedure.

The third stage is the man-machine interactive quality control of the resultant winds, which is performed by using graphic display and CRT-display of the IPC.

4.1 Automatic Assessment

The resultant vectors are assessed automatically by checking the following items on threshold values given as preset values, which are predetermined by another investigation. Each resultant vector is screened out automatically on the basis of the threshold values, and unrelisble vectors are rejected from the final reports.

(1) The features of matching surface

The parameterization of a matching surface is shown in Fig.7. A sample of a matching surface displayed on a graphic display was shown in Fig.5. The threshold values are determined by other investigation and are improved empirically. The relationship between R (the difference between dominant and second peak values) and D (the distance between dominant and second

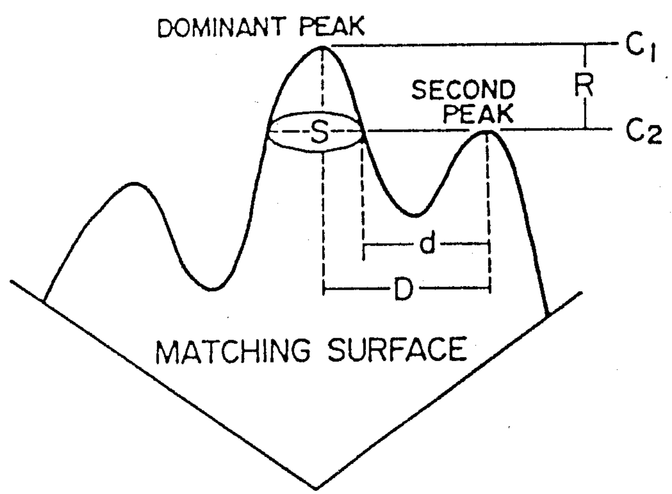


Fig. 7 Schematics of the parameterization of matching surface.

Table 3 Wind representative height to be assigned to high-level cloud motion winds derived from CWES system

SEASON		WINTER	SPRING	SUMMER	AUTUMN
NORTHERN HEMISPHERE	35°N	400 mb	300	250	300
	25°N	200	200	200	200
	EQ				
SOUTHERN HEMISPHERE		200	200	200	200
	25°S		300	400	300
	35°S	250			
SEASON		SUMMER	AUTUMN	WINTER	SPRING
		DEC 14/15 →	MAR 14/15 →	JUNE 14/15 →	SEP 14/15 → DEC 14

peak positions) is assessed automatically. In case R is smaller than its threshold value and D is greater than its threshold value, the vector is sent to manual check procedure. The relation of them is shown in Table 4.

(2) Picture-to-picture variation of cloud-top height

Two or three cloud top heights are extracted from a target cloud and the variations among them are checked automatically. Large variation of cloud top height is often caused either by developing/decaying cloud tracked or by the target cloud mistracked. Such vectors are to be rejected automatically in this procedure.

(3) Wind acceleration

The difference between two time-sequential vectors, V_{AB} and V_{BC}, is checked automatically. The difference between them is considered as the acceleration of the cloud motion. This procedure is effective in rejecting mismatched vectors.

(4) Missing line check on the images used for matching procedure

In case two/five lines or more are missing in infrared/visible template or search area, the derived vector is immediately rejected, because of no guarantee of resultant vectors.

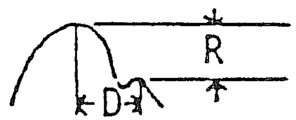
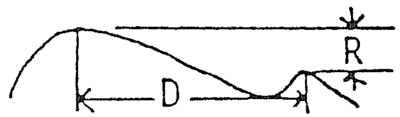
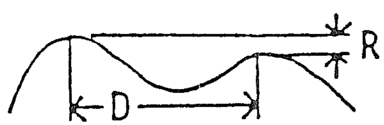
(5) Missing line check on infrared image used for CTH extraction

This is the missing line check on the infrared image which is used for CTH extraction. In case there are two or more missing lines, the CTH is not extracted from the image.
Functions described above are performed in the procedure of matching and height assignment.

4.2 Objective Quality Control

Three types of procedures for objective quality control are available in the CWES. Through these procedures unreliable data

Table 4 Automatic assessment on the multiple peaks of a matching surface

A view of matching surface with multiple peaks	Quality Flag		Result of assessment
	Distance (D)	Difference (R)	
	1	0	PASS
	0	0	PASS
	1	1	FAIL
	0	1	Sent to manual judgement

may be automatically rejected or flagged, and the flagged data are assessed in the process of man-machine interactive quality control shown in the following section.

a. Horizontal consistency check

A low/high-level cloud motion wind is compared with the mean vector of the neighboring same-level cloud motion winds within a certain distance.

b. Vertical shear check

A low/high-level cloud motion wind is compared with the mean vector of the neighboring different level (high/low) cloud motion winds within a certain distance. When the difference defined as vertical shear of the winds is smaller than a preset value, the very wind is flagged. This check is very effective when thin cirrus clouds are tracked as low-level winds in automatical process.

c. Comparison with numerical weather prediction wind

The cloud motion winds are compared with NWP wind data which is obtained from the 12-hour forecasts of NWP at the NWP Division,JMA. The comparison is conducted as follows;

(a) low-level winds are compared with the NWP's mean vectors which are in the nearest area

(b) high-level winds are compared with the NWP's mean vectors which are in the nearest area

4.3 Man-machine Interactive Quality Control

Man-machine interactive quality control is performed using a graphic display and CRT-display of IPC.

(1) Using CRT-display

a. Checking of the reasonableness of automatic tracking

The animation of three time-sequential images in a full earth disk form in low resolution on the CRT-display is displayed first. An operator can survey the overall synoptic pattern and the calculated winds coverage. The animation in higher resolution on the CRT-dkisplay is displayed on which the resultant vectors are color coded according to height : green for high level, light blue for low level, and red coded for the ones checked by the objective quality control. An operator examines the resultant vectors with the movement of the target cloud watching the animation. The winds which do not correspond to the movement of any cloud, which appear to be associated with stationary clouds, which are associated with the development of clouds, etc. are manually deleted. The red coded arrows give attention to an operator and are checked.

(2) <u>Using a graphic display</u>

a. <u>Checking on horizontal consistency</u>

On a graphic display the arrows of the cloud motion vectors are coded in the same color on the screen of the TV-display. Horizontal consistency of the resultant vectors is checked by displaying the resultant wind vectors on a graphic display.

b. <u>Comparison with radiosonde winds</u>

Resultant vectors are compared on a graphic display with radiosonde winds which are transmitted to the MSC through the GTS in real-time. The kinds of the radiosonde wind are coded white on a graphic display. Two kinds of comparisons are performed. One is a comparison of a resultant vector with a nearby radiosonde wind at the same altitude as the target cloud top height. Another is a comparison of a resultant vector with radiosonde wind at level-of-best-fit (LBF), at which the vector difference between both winds is the smallest. Through these comparison procedures, an operator checks the vector in question.

c. <u>Checking on the features of a matching surface</u>

Matching surface calculated in matching procedure is checked on a graphic display by inspecting the three dimensional features of the surface (Fig.5). This function is provided in order to determine the threshold values of the parameters specifying a matching surface shown in Fig.7. Usually this check is not used in routine operations.

In these procedures, except for the matching surface check, an operator can reject unrelialbe vectors.

5. DISSEMINATION AND ARCHIVING

The cloud motion wind vectors considered reliable through various quality control procedures are coded into WMO formats (SATOB) for transmission to Forecast Department of JMA via domestic communication system and to world-wide users via GTS within three hours from VISSR observation. These vectors are stored on archival data tapes, listed by a line printer and plotted on the maps of Mercator projections. The wind data on an archival data tape are stored in the international formats used for the Level II-b data exchange during the FGGE period. A reel of the tape (6250/1600bpi) includes 6-month wind data. These wind data are printed in the Monthly Report issued by the MSC. An example of resultant vectors derived in routine operation at 00UT, 4 November, 1988 are shown in Fig.8.

6. NOTE FOR USERS

The way of cloud motion wind derivation is much different from that of conventional wind measurements. So the quality and the characteristics are also much different from other types of winds from radiosonde, aircraft, etc. When the cloud motion winds are used together with those conventional winds for weather map analysis, it is important to understand the differences of the qualities and characteristics between both types of winds.

6.1 Representative Height of Cloud Motion Winds

(1) Low-level wind

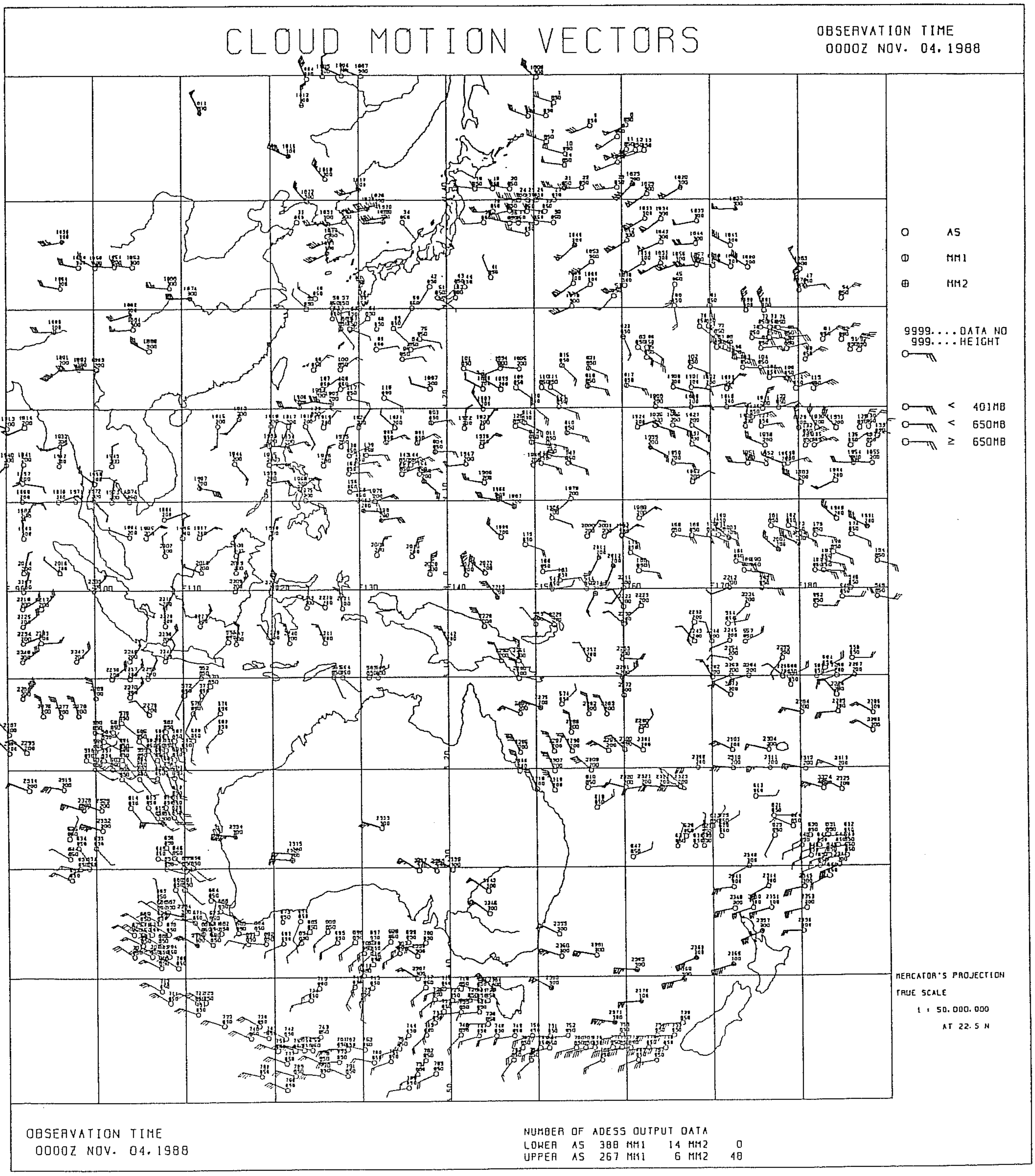


Fig. 8 Cloud motion winds derived from the GWES at 00UTC, August 3, 1988. Bold winds are high-level winds and others low-level winds.

It has been generally shown that the low-level cumulus clouds move with the environmental winds at the cloud-base. The MSC also made some statistical investigation on the difference between the winds from low-level cloud and from radiosonde observation.
As a result of the investigation, the cloud motion vectors agree best with radiosonde winds at 850hp or lower. It was impossible to focus the level of best fit to a certain level, because some of radiosonde stations do not report the winds at significant level. So the MSC assign 850hp to the height of low-level winds as an indication of the cumulus tracked winds.

(2) High-level winds

The target clouds for the estimation of high-level cloud motion wind are often thin cirrus clouds. It is difficult to estimate the exact cloud top temperature of the thin cirrus clouds from the infrared image, because there is no means to determine exactly the emissivity of thin cirrus. Therefore the MSC assigns the statistical LBF to the high-level cloud motion winds in the manner as described in Section 2.3.

6.2 The Time Interval of Images for Tracking

For cloud motion wind derivation, three time-sequential images are used. The high-level winds and the low-level winds are calculated from 2nd and 3rd images taken at 30 minutes interval. The images have horizontal granularity as shown in Table 5. The granularity causes the error of the resultant winds which is a function of the time separation of the images used for tracking as shown in the same Table. However, the actual errors are smaller than those values because the matching location is interpolated among discrete picture element's locations as described in Section 2.2.

6.3 Image Alignment

Alignment of the GMS VISSR images is performed using the coordinate transformation process from the predicted attitude and

Table 5 Image granularity and truncation error at sub-satellite(SSP).

Image	Granularity at SSP		Truncation error(30min.)
Visible	Pixel*	0.9km	0.5m/s
	Line*	1.25km	0.7m/s
Infrared	Pixel*	1.8km	1.0m/s
	Line*	5.0km	2.8m/s

*"Pixel" means the direction of east-west and "Line" north-south.

orbital data of the GMS. The orbit of the satellite is predicted daily using Trilateration Range and range Rate (TRRR) data which are measured four times a day through three ranging stations. The nominal error of the predicted satellite position in a day is the order of 100 m. The error is not so large as to cause significant image mis-alignment.

The attitude of the satellite is also predicted daily on the basis of the results of landmark matching procedure using several GMS VISSR visible images. The nominal error of the predicted satellite attitude is less than 140 radian of the spin axis direction. This corresponds to four visible pixels (picture elements), which causes 2.8 m/s of wind error at the sub-satellite point (SSP). However, the actual error in the calculation of the cloud motion winds comes mainly from the relative mis-alignment of two images used for tracking.

The mis-alignment between two images B and C sometimes gets to about 2 visible lines which causes the error of 1.4 m/s in v-component of the resultant winds. This error is caused by some small scale variation of the satellite attitude which cannot be determined/predicted by the current system.

In order to eliminate the error, the MSC developed a process for the fine tuning of the earth location in the image frame based on the earth edge detection from infrared full disc image.

6.4 Accuracy

The International Comparison of Satellite Winds has been carried out twice a year (for one month each) by CGMS. At the MSC the comparison is carried out at every observation and the statistics are obtained every month for assessment of the homogeny and accuracy of the satellite winds. The results of comparison between the GMS cloud motion winds and radiosonde winds are shown in Fig.9 and Table 6.

7. Estimation of ocean surface wind for typhoon analysis

A method of estimating ocean surface winds for a typhoon using

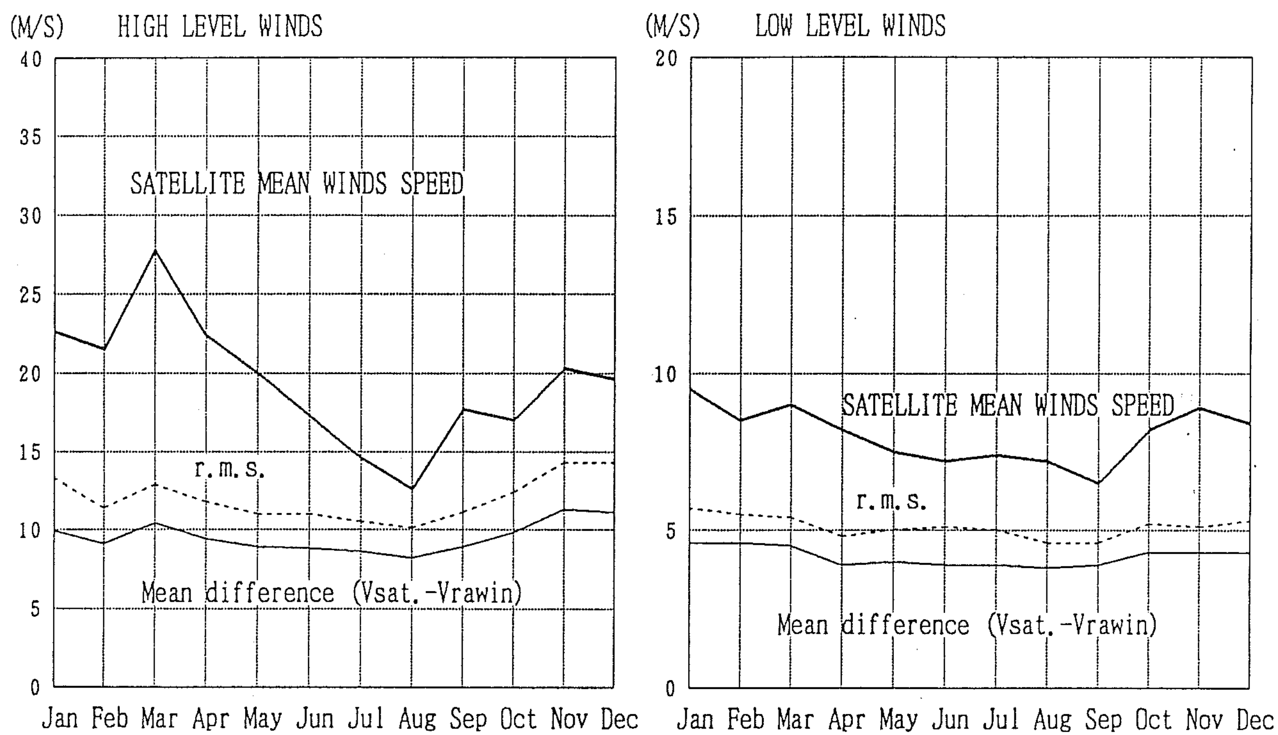


Fig. 9 Results of Comparison of Satellite Wind with Radiosonde Wind in 1988.
Vsat. : Vector of cloud motion wind, Vrawin : Vector of radiosonde wind.

Table 6 Results of comparison between the winds from the GMS cloud motion and the radiosonde observation.

Month 1987	No. of Comp. Data	Mean Sat. Wind	Vector Dif Abs. Mean	Vector Dif RMS	Speed Diff. (M/s) Alg. Mean	Speed Diff. (M/s) Abs. Mean	Speed Diff. (M/s) RMS	Dir. Diff. (Deg) Alg. Mean	Dir. Diff. (Deg) Abs. Mean	Dir. Diff. (Deg) RMS	U-Comp. (M/S) Alg. Mean	U-Comp. (M/S) Abs. Mean	U-Comp. (M/S) RMS	V-Comp. (M/S) Alg. Mean	V-Comp. (M/S) Abs. Mean	V-Comp. (M/S) RMS
Low-level Winds																
Jan.	647	8.9	3.7	4.5	-0.6	2.3	3.1	-1.2	22.7	37.8	-0.8	2.5	3.3	0.0	2.3	3.0
Feb.	463	8.4	4.0	4.9	-0.5	2.5	3.3	2.0	23.8	37.1	-0.6	2.6	3.4	0.2	2.6	3.5
Mar.	637	7.5	5.3	6.3	-1.2	3.6	4.9	0.5	35.3	50.3	-1.4	3.4	4.6	-0.1	3.3	4.3
Apr.	680	7.4	4.6	5.5	-0.6	2.8	3.8	-6.1	34.4	51.3	-0.8	3.0	4.0	0.1	2.9	3.8
May	477	7.1	3.6	4.3	0.2	2.0	2.7	-0.7	27.6	41.5	-0.8	2.3	3.0	-0.3	2.3	3.0
Jun.	531	6.8	3.9	4.9	0.0	2.3	3.1	-4.0	30.5	45.8	-0.4	2.4	3.5	-0.2	2.5	3.4
Jul.	594	7.8	3.8	4.9	-0.1	2.3	3.3	-5.3	25.8	39.9	-0.8	2.4	3.6	-0.4	2.5	3.4
Aug.	559	6.5	3.4	4.2	0.3	2.1	2.9	-4.4	27.2	40.8	-0.6	2.2	3.1	0.0	2.1	2.8
Sep.	703	8.0	3.9	4.7	0.5	2.6	3.5	-3.2	24.0	36.9	-0.2	2.2	3.0	-1.1	2.7	3.6
Oct.	792	8.1	4.3	5.3	0.0	2.6	3.7	-0.6	28.5	42.8	-0.7	2.6	3.6	-0.1	2.9	3.9
Nov.	679	8.2	4.4	5.2	-0.1	2.5	3.4	-3.9	31.4	47.8	-0.7	2.8	3.8	-0.2	2.7	3.6
Dec.	994	8.8	4.0	4.8	-0.4	2.4	3.1	0.0	24.8	39.0	-0.4	2.6	3.3	-0.3	2.6	3.5
High-level Winds																
Jan.	579	25.0	10.3	12.9	-2.3	7.2	10.1	0.9	17.2	28.5	-2.8	7.2	10.0	-0.3	5.8	8.1
Feb.	575	24.0	9.8	12.4	-2.0	7.1	10.0	3.3	17.6	27.9	-1.9	7.0	10.2	0.1	5.4	7.1
Mar.	486	26.6	10.4	12.9	-5.0	7.8	10.8	-1.4	16.0	27.3	-4.8	7.8	10.8	0.4	5.3	6.9
Apr.	1202	22.9	9.3	11.8	-4.3	6.9	9.9	-0.4	15.1	23.7	-3.8	6.6	9.4	-0.1	5.2	7.1
May	1450	21.0	8.7	10.7	-2.7	6.1	8.5	-0.8	17.6	27.8	-2.1	5.8	7.9	-0.6	5.3	7.1
Jun.	1692	18.7	8.8	11.0	-2.6	6.0	8.5	-0.2	22.8	36.2	-2.0	5.7	8.1	-0.3	5.4	7.4
Jul.	1630	16.5	8.6	10.6	-3.2	5.7	8.1	-3.7	26.1	41.1	-1.0	5.7	7.9	0.7	5.3	7.1
Aug.	1787	14.8	8.6	10.7	-3.9	6.0	8.6	-0.4	26.3	40.9	-2.5	5.8	8.2	0.3	5.1	6.8
Sep.	1480	17.8	8.9	11.3	-3.7	6.4	9.0	-2.0	21.4	34.0	-1.8	5.8	8.1	-0.2	5.6	7.8
Oct.	1163	19.0	8.6	10.7	-3.3	6.1	8.6	-0.5	22.4	37.8	-2.7	6.0	8.4	0.1	5.0	6.7
Nov.	1035	23.5	10.2	12.9	-5.4	7.9	11.1	-1.5	17.9	30.6	-3.8	7.5	10.4	-0.4	5.4	7.6
Dec.	769	20.9	10.1	13.1	-5.5	7.7	11.4	-0.6	21.5	35.3	-4.2	7.3	10.8	-2.0	5.4	7.4

the cloud motion winds derived from short-time interval images has been developed at JMA/MSC.

The cloud motion winds from satellite images are useful source in the data sparse area over the ocean. If the low-level cloud motion winds can be used to estimate the wind field of a typhoon, it is expected to contribute to a better issue of the tropical cyclone forecast, warnings and advisories.

In order to use the cloud motion winds in a typhoon area, it should be considered that ; (a) number of the low-level cloud motion winds derived routinely is not sufficient to analyze the wind field for a typhoon and (b) conventional method of estimating the surface winds from the low-level cloud motion winds is not established in a typhoon area. It has been investigated to solve these problems.

This type of winds measurement is still in the experimental stage, which means that the measurement results are not used for the NWP.

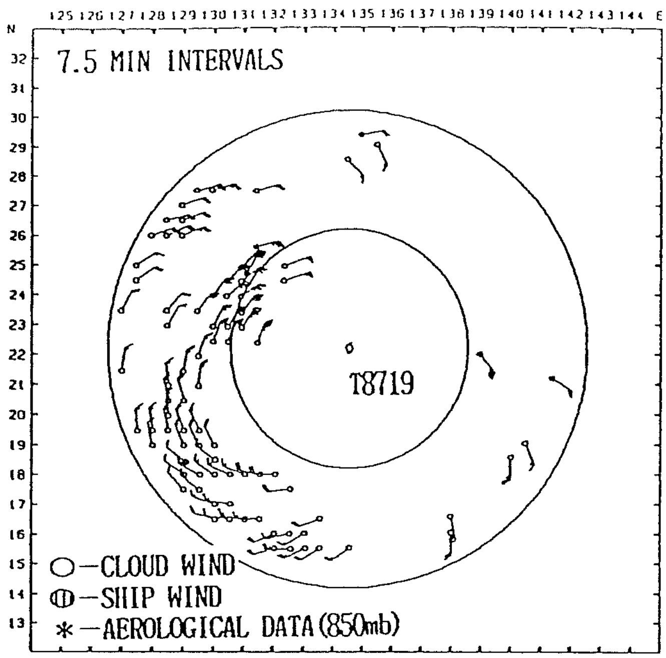
7.1 High density derivation of the low-level cloud motion wind from the short-time interval GMS images

The cloud motion winds are derived routinely using 30-minute interval sequential images from GMS. However, it is difficult to derive automatically the low-level cloud motion winds from 30-minute interval images in a typhoon area, because the low-level target clouds are liable to be covered by the cirrus and change considerably their shape in a typhoon area.

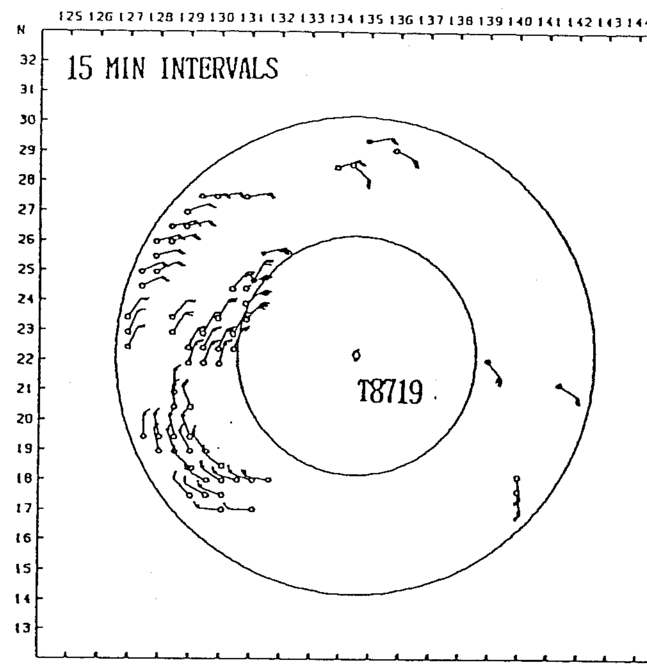
In order to increase the number of the low-level cloud motion winds in a typhoon area, thirteen sets of the short time interval images were taken for seven typhoon in 1987 typhoon season. The low-level cloud motion winds for a typhoon were derived automatically from 7.5-minute, 15-minute and 30-minute interval images and three data sets in each different time intervals were produced. Examples of the derived winds in the typhoon area are shown in Fig.10. Each two sets among them were compared respectively.

It was found that the low-level cloud motion winds derived from

(a)



(b)



(c)

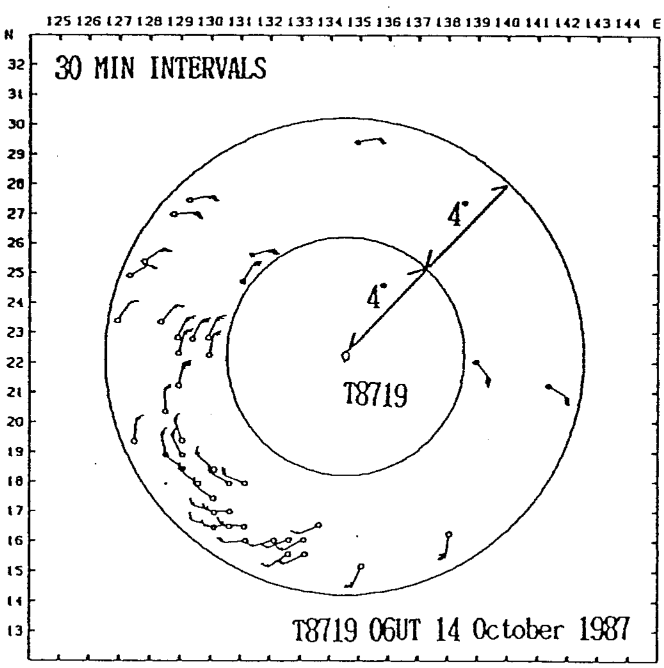


Fig. 10 The low-level cloud motion winds on 14 October 1987 for Typhoon Kelly, the ship wind and the aerological wind.

The ship winds and the aerological winds at 850mb level on 06 UT are used.

(a) The low-level cloud motion winds are derived from three consective images observed at an interval of 7.5-minute.

(b) Same as (a), except with an interval of 15-minute.

(c) Same as (a), except with an interval of 30-minute.

the shorter time (7.5 or 15 minutes) interval images have more advantages than those from 30-minute interval images. The shorter time interval images make it possible;

(a) to derive the low-level cloud motion winds in the nearer area of the typhoon center,
(b) to provide large number of the low-level cloud motion winds in the typhoon vicinity, and
(c) to express the ocean surface wind profile as a function of a distance from the typhoon center (Fig.11).

Moreover, it was indicated that the derived winds did not change their characteristics according to the different time intervals. Furthermore 15-minute interval imaging is suitable to be routinely used to derive the low-level cloud motion winds for a typhoon, because 15-minute interval imaging is not necessary to change the position of imaging according to a typhoon location and by other reasons.

7.2 Method of estimating the ocean surface wind from the low-level cloud motion winds

Because the sample number of the winds derived automatically from the short time interval images described in previous section was not sufficient to compare with the ship observed winds, the low-level cloud motion winds were manually derived by analysts from 30-minute interval images which were used for routine wind derivation. Forty-three data sets of the low-level cloud motion winds were produced in the typhoon area, and were compared with the nearby ship observed winds.

These comparisons were carried out on the relative direction of winds (Fig.12(b)) and on speed as a function of a distance from typhoon center.

It was found that ;

(a) the mean direction of the ship observed winds gets into the typhoon center about 30 degrees more than the cloud motion winds at the distance of 200km to

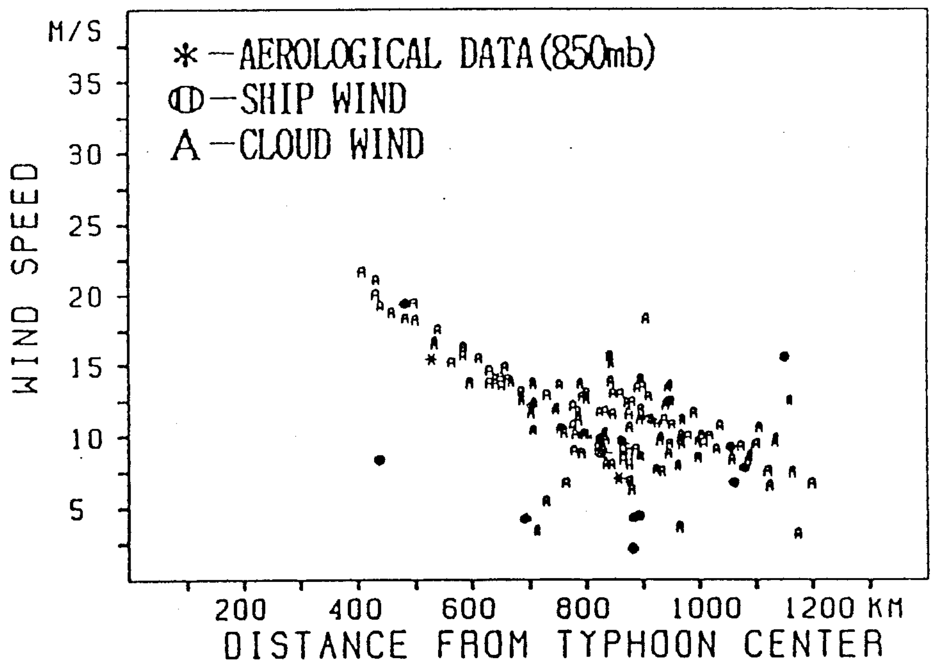
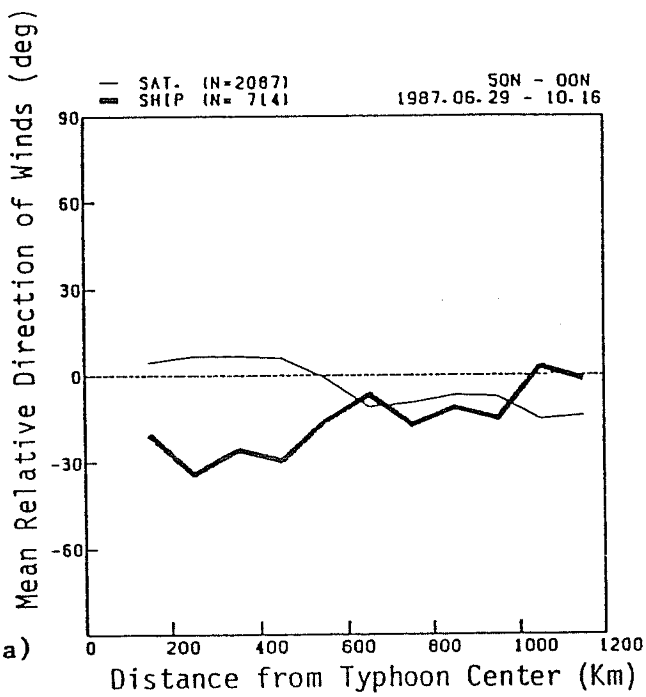
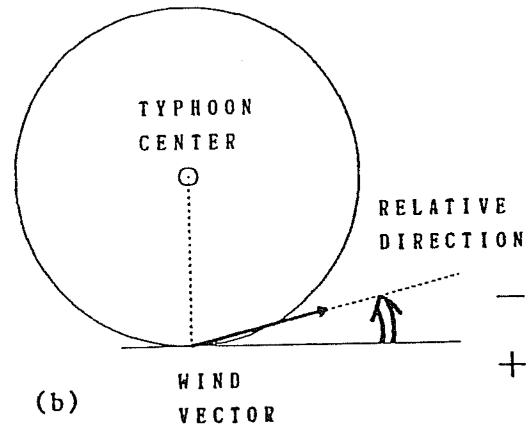


Fig. 11 The speed profile of the low-level cloud motion wind, the ship wind and the aerological wind as a function of a distance from the typhoon center.

The low-level cloud motion winds from the 15-minute interval images are plotted. The ship wind and the aerological winds are the same as in Fig. 10



(a)



(b)

Fig. 12

(a) The mean 'relative direction (see Fig. 12(b))' of winds at interval of 100km from the typhoon center.

Thin line shows that of the low-level cloud motion winds and thick line that of the ship observed winds.

(b) Relative direction

This is a relative angle of the wind vector to the direction of the tangential line, drawing a circle round a typhoon center. The side which gets into the center of a typhoon at the base of tangential line is minus angle of direction.

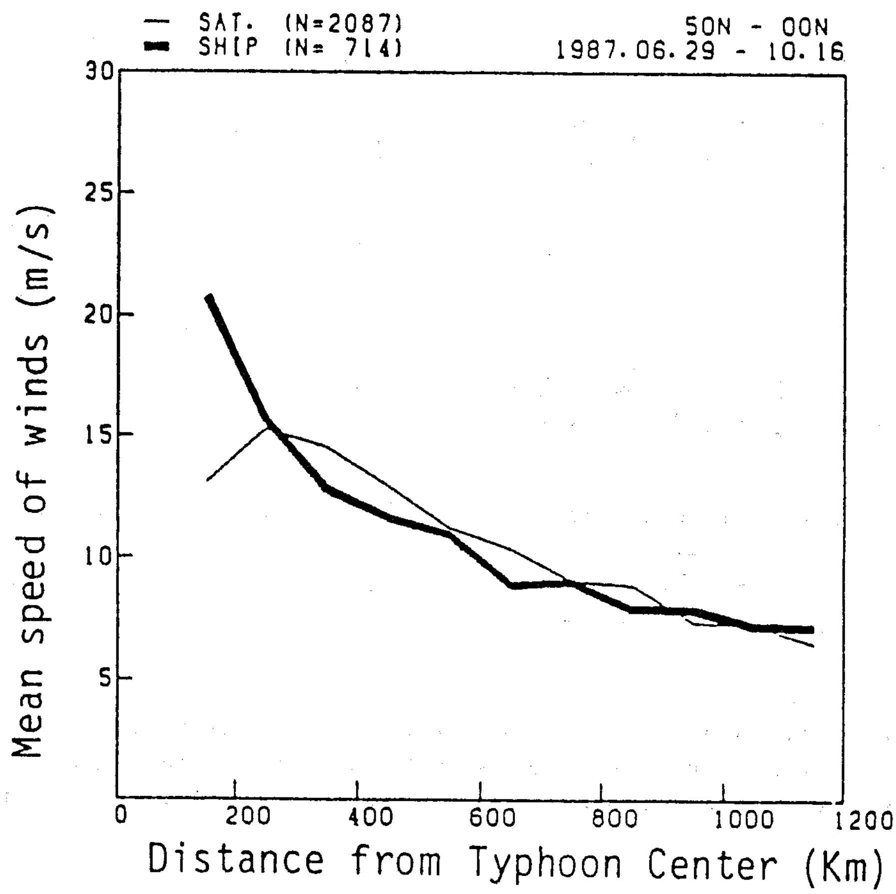


Fig. 13 Same as Fig. 12(a), but for the wind speed.

500km from the typhoon center (shown in Fig.12(a)), and

(b) the mean speed of the low-level cloud motion winds is almost a tenth again as fast as that of the ship observed winds at the distance of 300km to 700km from the typhoon center (shown in Fig.13).

These results show that the ocean surface wind can be estimated by correcting the cloud motion wind.
If the cloud motion winds for a typhoon are derived from the short time interval images, and that ocean surface wind in the typhoon area be estimated from the cloud motion winds.
For further confirmation of the results described here ,the 15-minute interval imaging and the low-level cloud motion wind derivation have been routinely carried out whenever there is a typhoon in the western Pacific Ocean of northern hemisphere.

8. Conclusion

In this report the current Japanese Cloud Track Wind Measurement System, which was made mainly based on 'The GMS User's' Guide' and the 'Meteorological Satellite Center Technical Note'.
The MSC will continue to improve this system, on the other hand, the MSC will develop some new technique for the best use of the GMS-5, which will be launched in 1994 and installed new infrared sensors, i.e. 10.5-11.5μm, 11.5μm and 6.0-7.0μm.
The author would like to acknowledge the help given by the staff members of the MSC in preparing this report.