Man-machine Interactive Processing of Extracting Cloud Top Height and Cloud Wind Data from the GMS Images

Abstract

GMS views the earth's scene through the VISSR (Visible and Infrared Spin Scan Radiometer) instruments. The meteorological information like those cloud drift winds, cloud top heights are extracted from image data ingested from VISSR. Computerwise, it is very hard to parameterize cloud features. The eye-brain skills are the only means for extracting useful information from image data. The systems mentioned above are designed to combine the eye-brain skills with a high-speed processing based on large scale computer.

The image data are displayed on a TV-screen of the IPC (Image Processing Console) to manipulate them for man-machine interactive processing. In this processing, an analyst selects a target cloud on the TV-screen and inputs the needed information from IPC to command the computer for calculating the results. To maintain high quality of the results, the quality checks are also done man-machine interactively using IPC and graphic display (GD). After the quality checks, the cloud drift winds are reformatted by computer into a WMO code form for teletype transmission to world-wide users twice a day within four hours after the observation. The cloud top heights are used for the production of neph-analysis chart which is sent to final users as facsimile chart four times a day.

The GMS Cloud Wind Estimation System (CWES) and Cloud Top Height Estimation System (CTHES) are described herein stressing the man-machine interactive procedures.

Introduction.

GMS (Geostationary Meteorological Satellite) views the earth disk through VISSR (Visible and Infrared Spin Scan Radiometer). GMS is positioned at 140°E above the equator, altitude of about 36000 km. The VISSR provides concurrent observations in the infrared (IR) spectrum (10.5–12.5 μm) and in the visible (VIS) spectrum (0.5–0.75 μm). These observations are transmitted to ground at periodic intervals, usually every three hours. About 25 minutes are required for the VISSR to produce the digital image data of the full earth disk.

The computer facility located at MSC (Meteorological Satellite Center) provides

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the large scale computer for an image data processing. The configuration of computer system consists of four FACOM 230-75 computers. The computer complex is mainly devided into two systems, "on-lines system" and "batch system". The batch system has a responsibility of extracting meteorological information such as cloud drift wind vector (CWV) and cloud-top height (CTH). The overview on the utilization of GMS satellite is described by Murayama et al. (1978).

We have developed man-machine interactive processings for extracting CWV's and CTH's because there are some difficulties for selecting clouds and assigning emissivities to target clouds. Skilled analyst inspects synoptic cloud patterns, selects target clouds and assigns emissivities for CWV and CTH extraction.

In our systems, Cloud Wind Estimation System (CWES) and Cloud-Top Height Estimation System (CTHES) are our approach to introducing human expertise into an automatic procedure. Wind derivation system and its limitation of current method are described by Hamada et. al. (1978A, 1978B). Detail procedures of CTHES system and CWES system are described in Part I and Part II in the article respectively.

Part-I. GMS Cloud Top Height Estimation System.

MMIPS (Man Machine Interactive Processing System) at NESS (National Environmental Satellite Service, Bristor, et al.; 1975) and McIDAS (Man-Computer Interactive Data System, Suomi; 1975) at the University of Wisconsin had been developed. These systems have a function of cloud top height estimation.

The total radiation sensed by the GMS represents the sum of target cloud radiance and that from the underlying sea surface or low level cloud. The Cloud Top Height Estimation System (CTHES) is developed at MSC (Meteorological Satellite Center) to derive a cloud top height (CTH) by means of man-machine interactive processing. Derived CTHs are the most basic information for interpreting cloud features such as extension of cloud tops, their flatness, convective activities. These information are typically depicted on "Neph-Analysis Chart" which is one of the product on routine base at MSC.

1. Basic Equation.

The blackbody temperature of a cloud equals the actual cloud top temperature if the cloud is dense to shield the infrared sensor from radiance below the cloud. In general, actual clouds are not dense enough optically, so the radiance sensed by satellite represents the sum of cloud radiance and that from underlying surface. The relationship between the cloud top temperature and the measured blackbody temperature can be expressed by the following equation considering the atmospheric attenuation correction (AAC).

$$N(Tbb)=eN(Tc)+(1-e)N(Ts-t+dt) \quad (1)$$

where,

$N(Tbb)$: Radiance from the cloud observed by satellite.

$N(Tc)$: Radiance from the cloud.

$N(Ts-t+dt)$: Radiance from underlying surface (sea or low level cloud).

Tbb: Representative blackbody temperature of cloud observed by satellite.

Tc: Blackbody temperature of cloud.

Ts: Blackbody temperature of underlying surface.

t: Total atmospheric attenuation correction value (from surface to a top of atmosphere).

dt: Atmospheric attenuation value (from cloud top to the top of atmosphere).

e: Cloud emissivity which is estimated on the basis of empirical rules.

The quantity related to atmospheric attenuation correction can be estimated under the condition of the vertical profile of atmosphere and optical path length are known. Apart from this problem, $N(Tbb)$ and $N(Ts)$ are measurable quantities but a cloud emissivity is not measurable objectively. These three basic parameters are needed for solving the radiation equation.

Fig. I-1 illustrates the equation (1) schematically. The total atmospheric attenuation correction value (t) is calculated

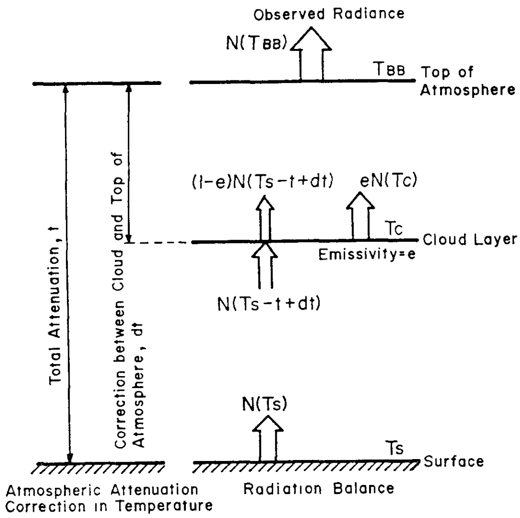


Fig. I-1 Schematic diagram of radiation balance in related to Eq. 1.

using precipitable water based on climatological data, named GMSSA (see, section 3). An underlying surface (temperature, T_s) emits radiance $N(T_s)$. When it reaches to the bottom of cloud layer, the radiance decreases to $N(T_s-t+dt)$ caused by atmospheric attenuation. It penetrates through the cloud layer (emissivity, e and temperature, T_c), and upward $(1-e)\cdot N(T_s-t+dt)$ is re-emits from the cloud top. On the other hand, the cloud layer emits the upward radiance $e\cdot N(T_c)$ originally. The total radiance sensed by satellite is the sum of two sources of radiance.

2. Basic Parameters.

2.1. Representative Blackbody Temperature (*Tbb*).

To estimate *Tbb*, a histogram analysis is performed within a target cloud area. This area contains typically 17 lines by 45 overlapped pixels along a scan lines. In this case, this area size is about 85 km on a side at the sub-satellite point (SSP). The histogram based on the samples of infrared (IR) image data produces usually a multimodal histogram. The cold mode represents a temperature of cloud area, and the warm mode yields a temperature of cloud free area. These two modes can be distinguished themself by comparing a threshold value which is empirically defined as Ts-A. Each sample warmer than the threshold value is discarded from a total sample. Retained samples are distributed in the histogram which contains a single mode associated with a cloud top temperature.

Following three values are available for deciding *Tbb* from the histogram, as shown in Fig. I-2.

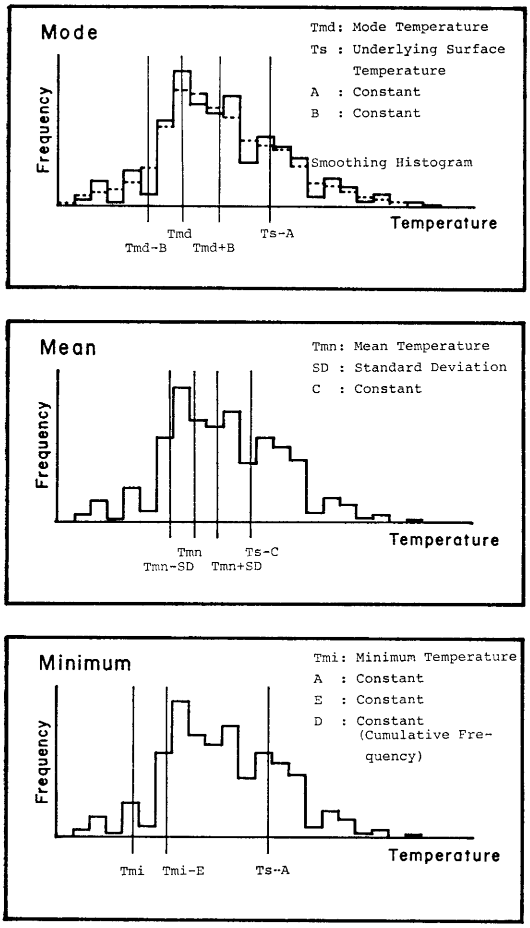


Fig. I-2 The diagram showing how to estimate representative temperature over target cloud area.

(1) Mode value

Mode value is regarded as *Tbb*. This is adopted to "Synoptic Scale Cloud Top Height Estimation System" as describes in Section 4. 1.

(2) Minimum value

Tbb defined as minimum value is adopted to a cloud drift wind height assignment and "Meso-Scale Cloud Top Height Estimation System" as describes in Section 4. 1.

(3) Mean value

This is an optional method. Mean value is assigned to *Tbb*.

The method (Mode, Mean, Minimum) to determine representative temperature can be used by an analyst. For separating the cloud area and sea surface which are co-located within a target cloud area, a temperature of pixel is compared with the threshold value (T_s-A, for the Mode; T_s-C, for the Mean).

A cumulative frequency derived from temperature interval $T_{md}-B$ and $T_{md}+B$ is a kind of concentration factor around T_{md}. This factor is used for estimating a validity of mode value.

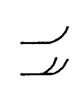
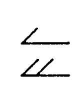
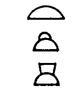
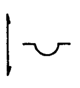
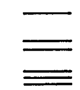
The cumulative frequency constant (D) counted up from the lowest temperature is set to eliminate an effect of noise. The constant (E) is a kind of shape factor indicating a gradient around the minimum temperature (T_{mi}). T_{mi} is defined from D.

2.2. Cloud Emissivity (e)

The emissivity is primarily a function of the opacity of the cloud. The convective clouds tend to radiate almost as blackbodies ($e=1$) but other types clouds display emissivities that range from less than 0.1 up to nearly unity. The emissivity is sensitive for the CTH estimation. To reduce uncertainty in emissivity estimates, the CTHES adopted an empirical relation (e. g. Allin, 1971) between an emissivity and a cloud type, its opacity (or cloud thickness). This is summarized in Table I-1. An analyst makes decision as to only cloud types and their opacities, then the emissivity is inferred from this table.

When a thin cirrus cloud is occurred in a target cloud area, a tropopause level is accepted as the CTH because some observational facts indicate that this type of cloud has almost the same height as the tropopause level.

Table I-1 Empirical cloud emissivities and thier thickness.

Cloud types and thickness		Emissivity	Legend
Cirrus	Thin	—(%)	
	Medium	—	
	Dense	60	
Altostratus	Thin	—	
	Medium	70	
	Dense	90	
Altocumulus	Thin	50	
	Medium	80	
	Dense	90	
Cumulus	Thin	80	
	Medium	90	
	Dense	100	
Stratocumulus	Thin	30	
	Medium	70	
	Dense	90	
Stratus	Thin	60	
	Medium	80	
	Dense	100	
not specified		—	*

2. 3. Underlying Surface Temperature (Ts)

The radiance from underlying surface is not inferred from the satellite when a target cloud is covered with an emissive cloud. This causes an unestimation of Ts. Instead of a direct temperature measurement of Ts, that is accomplished by MMIPS operation (Bristor, et al; 1975), the CTHES uses a satellite derived sea surface temperature (SST). This data set is routinely produced every ten days (at the grid point values of one degree interval in latitude and longitude). If the SST data is not available, a surface temperature obtained from climatological data which describes in Section 3.

The cloud temperature Tc can be derived from the equation (1) by the use of these three parameters, Tbb, Ts, and e.

3. Conversion to Cloud Top Height.

The conversion of cloud top temperature (CTT) into cloud top height (CTH) is performed based on a vertical temperature profile (VTP) data. The data set is reconstructed from the climatological data (NCAR; 1971 and U. S. NAVY; 1970). This is provided in the form of monthly mean-grid point value with five-degree intervals in latitude and longitude, and named "GMS Standard Atmosphere (GMSSA)".

As daily operation, an actual VTP is simulated by the GMSSA data referring the result of air-mass analysis. Once a location of target cloud area is designated, the derived CTT is referenced to the VTP data at the nearest grid point.

4. System Configuration and Function.

The configuration of the CTHES software is summarized in Table I-2, and the functional block diagram is shown in Fig. I-3.

4. 1. Cloud Top Height Estimation Job Groups

This is the core of model. These job groups are divided into two groups. One of these, the Large Scale CTHE aims to derive the CTHs associated with a large scale meteorological disturbance. An interest area is mainly restricted to a northern hemisphere. A target cloud area size is chosen normally 17 lines by 45 pixels and used the mode value for Tbb. The rest is "Meso Scale CTHE". It intends to an effective means for the CTHs corresponding to a meso-scale disturbance. An interest area is Japan and its vicinity. A target cloud area size is normally selected

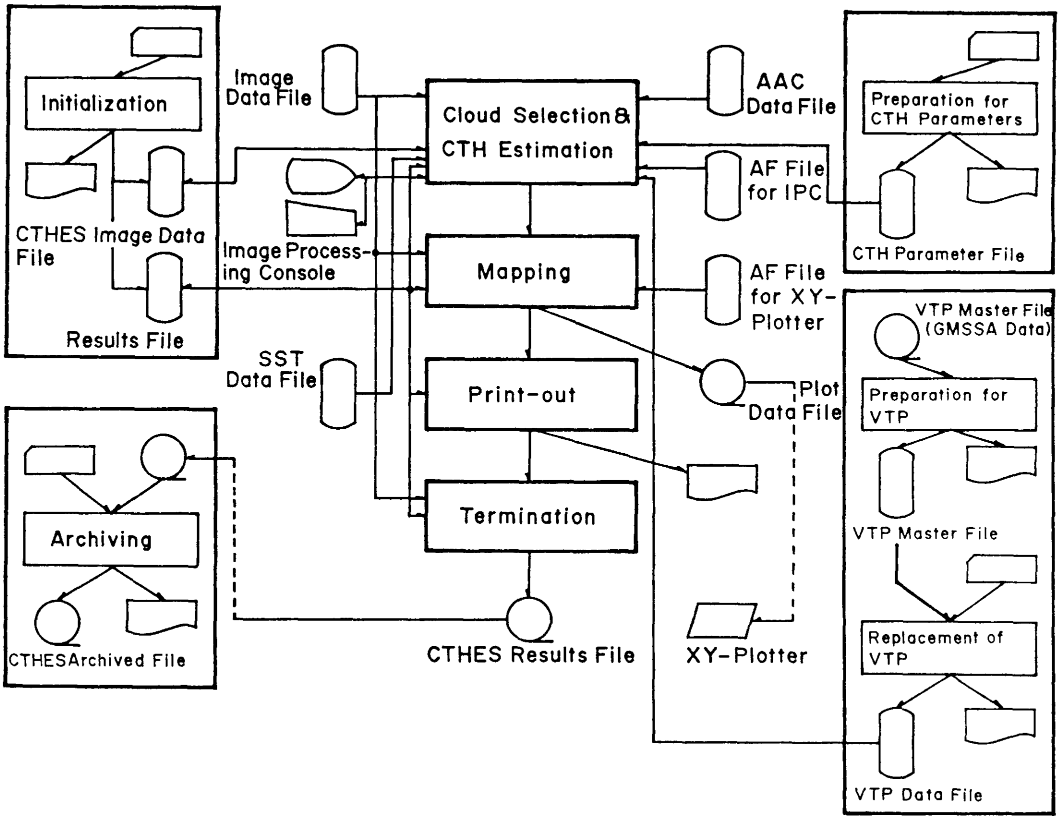


Fig. I-3 System configuration and functional block diagram of the CTHES.

Table I-2 Soft-ware construction of the CTHES.

Cloud Top Height Estimation System (CTHES)	
Job Groups	**Programs**
Cloud Top Heigt Estimation (CTHE) Synoptic Scale CTHE Meso Scale CTHE	Cloud Selection & CTHE Mapping Print-Out Termination
Vertical Temperature Profile (VTP)	Preparation for VTP Replacement of VTP
Support File Creation Archiving of CTH Data	Initialization Preparation for CTHE-Parameters

9 lines by 23 pixels, and uses a minimum value for *Tbb*.

These job groups consist of the following programs.

(1) Target Cloud Selection and Cloud Top Height Estimation

This program allows an analyst to estimate CTH on the basis of a man-machine interactive procedure. As a visualization system, "Image Processing Console (IPC)" is equipped for displaying various kinds of image data in black and white (B/W) or color. The following operations can be selected on the basis of analyst's command.

a) Visible (VIS) and IR image data within the interest area are displayed immediately on the IPC with original spatial resolution or reduced one.

b) VIS and IR image data which are independently colored, are superimposed and displayed. The cloud type and thickness are distinguishable inspecting this display.

c) Pseudo-colored IR image data are displayed to examine "thermal slice profile" around the target cloud area.

d) Gray-scale or color-bar scale/VIS-count or IR-count conversion curves are displayed to handle them. This permits the analyst to enhance a cloud feature.

e) Target cloud selection is accomplished by moving a target selector with "Positioner". After centering the target cloud within this selector, the analyst informs a location of target cloud area and its size to computer via "Send Position Key".

f) Using a keyboard and/or a function key, the analyst issues command to the computer on the basis of derived relevant information such as cloud type and thickness, under the inspection of displayed image data. Derived CTH is displayed immediately on the IPC. He can try again performing the same procedure if the estimation is not acceptable.

(2) Mapping

Derived CTHs are mapped on the *X*−*Y* plotter through this program. The symbolized cloud types, shown in Table I-1, and other information such as CTT, *Tbb*, and standard deviation estimated from the traget cloud area are also added to the map. A sample of this is shown in Fig. I-4. The map delivers to the neph-analy-

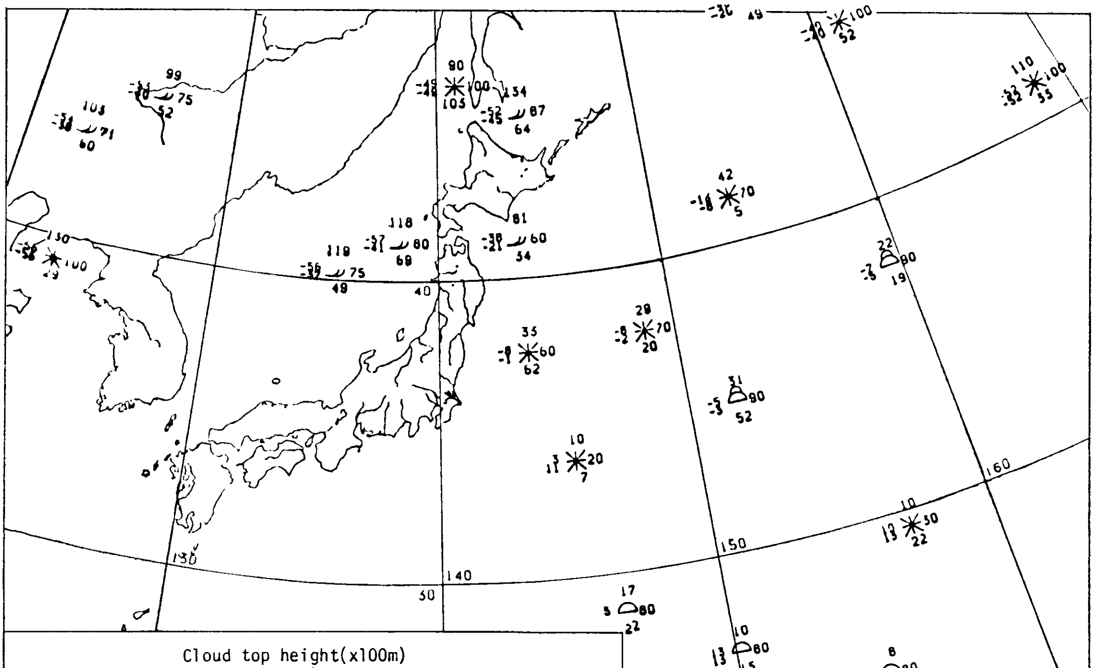


Fig. I-4 A sample of cloud top height data display.

sis section.

In the case of the Meso-Scale CTHE, this program is ignored.

(3) Print-out

All kinds of information needed for investigating the results are output to the line-printer. The frequency distribution derived from traget cloud area is available. When the Meso-Scale CTHE is performed, a temperature array display related to target cloud area is available.

(4) Termination

Once the target cloud selection and cloud top height estimation procedure is completed, derived CTHs data are stored on a magnetic tapes, named "CTH results file". The disk files used for the CTHES are also terminated.

4.2. Vertical Temperature Profile Job Group

This job group provides the most optimum VTP data on the disk file, named "VTP Data File". The temperature/height conversion and atmospheric attenuation correction procedure access to this file. The job group consists of the following programs.

(1) Preparation for VTP

The GMSSA data are stored on a magnetic tape. A disk file is generated from this magnetic tape through the program. This file, named "VTP Master File", is maintained as a permanent file.

(2) Replacement of VTP

Once air-mass analysis is completed, the results are punched on the cards. In this case, a name of month is used for a keywards. The contents of the VTP Master File is replaced according to the keywards. This program runs twice a day routinely.

4.3. Support Job Group

This provides the support programs for creating a file, and archiving the CTHs data.

(1) File Creation

a) Initialization

This program set up a system status. A disk file initialization is done. After this procedure, the CTHES image data file and results file become accessible.

b) Preparation for CTHE Parameters

Needed parameters which are mainly decided on the empirical bases are prestored on "CTHES Parameter File" through this program. This enables the analyst to replace the parameters as his requests. If not so, the parameters are retained and regarded as "nominal values". These parameters are as follows.

- Parameters needed for the histogram analysis.
- Empirical cloud emissivity/cloud type and its thickness.
- Gray-scale or color-bar scale/VIS-count or IR-count conversion tables.
- Location and coverage of sectorizing image data.

(2) Archiving of the CTH Data

The CTHES Results Files are produced four reels of magnetic tapes per day. This program makes them a single file and output to a magnetic tape. The orbital data, blackbody temperature/radiance conversion table, temperature arraies related to the target cloud areas and other information are added on this tape. This tape is archived on the routine bases for future investigation.

Part-II. GMS Cloud Wind Estimation System.

The technique to derive cloud drift winds using animated film-loop was developed by Prof. Fujita, the University of Chicago, soon after launch of the first Spin Scan Cloud Camera installed on the Application Technology Satellite (ATS 1) late in 1966. Leese et al. (1971) applied a cross-correlation technique to derivation of a cloud displacement for the first time. It made possible to extract a large number of cloud drift winds routinely.

Now the European Space Agency (ESA), the National Environmental Satellite Service (NESS), U. S. A. and Meteorological Satellite Center (MSC), Japan produce cloud drift winds, reformat them into a WMO code and transmit them to world-wide users twice a day. These cloud drift wind data are expected to be valuable data especially over the data sparse areas, ocean area, desert area and mountain area, especially for the input of numerical prediction processings.

Japanese system, GMS Cloud Wind Estimation System (CWES), has man-machine interactive processings and automatical processings. Skilled analyst selects suitable target clouds man-machine interactively, then the computer automatically tracks them to get the cloud displacements, and the analyst makes a quality control of them interactively. Finally reliable vectors are transmitted to world-wide users by Global Telecommunication System (GTS).

The processings operated by ESA, NESS and MSC are to be issued from WMO as Technical Note. Detail processings at NESS are described by Bristor (Editor), 1975. Detail processings of CWES system is described in the article.

1. GMS Cloud Wind Estimation System.

GMS Cloud Wind Estimation System (CWES) has three procedures, MM-1, MM-2 and Film-Loop (FL). The former two are man-machine interactive procedures and the latter is film-loop procedure, as shown in Table II-1. All vectors derived from these procedures are quality-controlled and transmitted to world-wide users by Global Telecommunication System (GTS). The general flow of these procedures is shown in Fig. II-1.

2. Registration of image.

Registrations of the GMS VISSR images are performed in the coordinate transformation process using attitude and orbital predicted data of GMS satellite.

Orbit of the satellite is predicted daily using Trilateration Range and Range Rate (TRRR) data which are measured four times a day using three ranging stations, Hatoyama, Japan, Ishigaki-jima, Japan and Orroral Valley, Australia. Nominal error of the predicted satellite position in a day is about 100 m. The error is not so large as to cause significant misregistration of VISSR images.

Attitude of the satellite is also predicted daily on the basis of the results of man-machine interactive land mark matching procedures using several VISSR visible images. The nominal error of the predicted satellite attitude is less than 140 μrad of spin axis direction. This causes misregistration of four visible pixels (picture elements) and 2.8 m/s of wind

Table II-1 The procedure of wind derivation in GMS Cloud Wind Estimation System.

GMS Cloud Wind Estimation System (CWES)	Man-machine interactive procedures	Manual target cloud selection & automatical tracking (MM-1 procedure)
		Manual target cloud selection & tracking (MM-2 procedure)
	Film-Loop procedure	Manual target cloud selection & tracking (FL procedure)

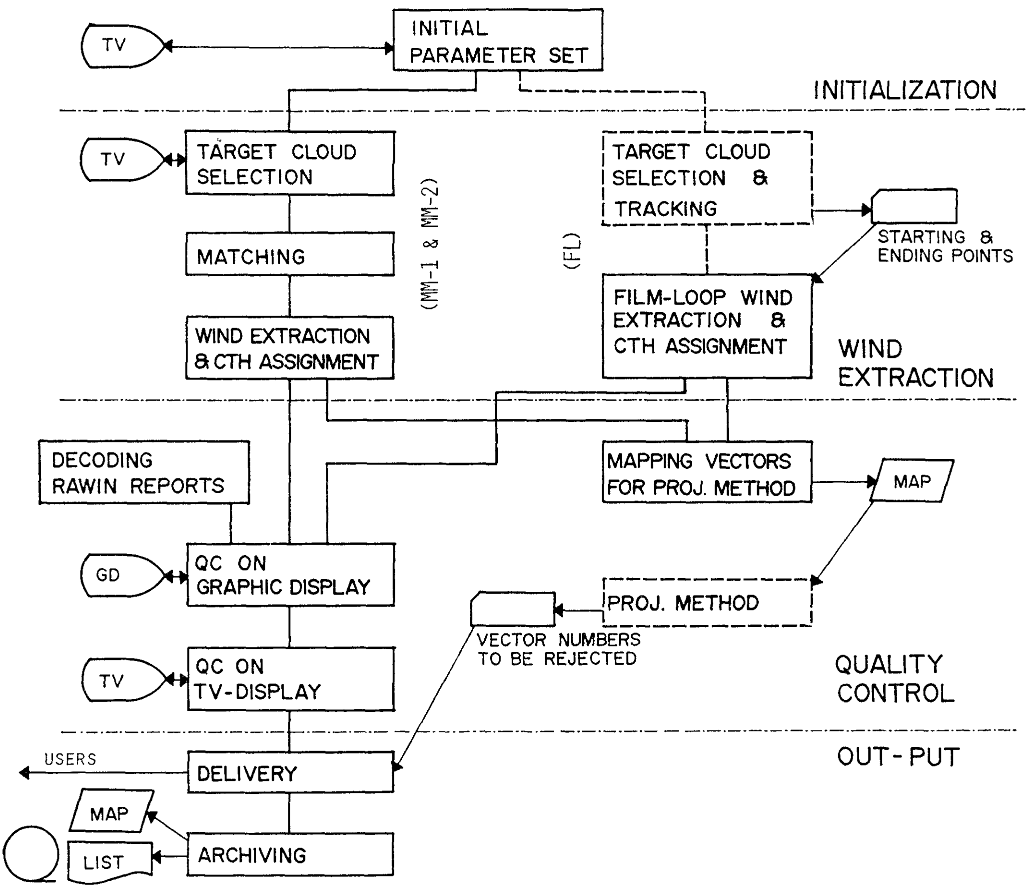


Fig. II-1 General flow of CWES system. "CTH" means cloud top height.

error at sub-satellite point (SSP). However, actual error of cloud drift winds mainly comes in when we take relative misregistration of two images. Our investigation shows that the misregistration among images used for deriving winds by CWES system is less than one visible pixel (Hamada et al., 1978B).

Consequently registration accuracy of VISSR images are good enough to derive cloud drift winds by CWES system.

3. Wind derivation.

3.1. Man-machine interactive procedures for target cloud selection

In this section man-machine interactive procedures of MM-1 and MM-2 are briefly described.

Image Processing Console (IPC) used for man-machine interactive processing, is equipped with TV-screen, cursor dial for positioning on the screen, alpha-numeric key for commanding a computer and function key, Usually three TV-screens, two for black-and-white and one for color, are used for displaying. Images with original spatial resolution are displayed on two TV-screens, black-and-white and color each. The visible and/or infrared images covering same area of about 600 km square are displayed using different enhancement tables.

Black-and-white screen

(a) Black-and-white visible or infrared image to be used for target cloud selection and tracking.

Color screen

(b) Pseudo-colored visible or infrared image is displayed by manual selection of analyst.

(c) Both visible and infrared images are simultaneously displayed in different monocolors in order that analyst inspects the characteristics of clouds.

(d) Time sequential two or three images are simultaneously displayed in different monocolors in order that analyst inspects the development and displacement of clouds. In MM-2 procedure, target clouds are selected and tracked by analyst on the TV-screen thus displayed.

Another black-and-white TV-screen is used for displaying whole disk image or sampled image covering one sixteenth of the whole disk, in order that analyst may inspect the synoptic pattern of clouds to get information on cloud target selection.

(1) MM-1 procedure

On color or black-and-white screen displayed in original spatial resolution, analyst moves cross mark cursor to select target clouds for tracking. In routine operation, sequential images are usually displayed on color screen so as the analyst may classify usable "passive tracer" as shown by Hubert et. al. (1971). After selecting target clouds, analyst gives an emissivity value of the cloud to estimate cloud top height from infrared data. The operation described above is repeated about 200 times. Information on the location of selected points and assigned emissivities are accumulated in a disk pack for successive processing.

(2) MM-2 procedure

On color screen displayed by time sequential images in different colors, analyst selects both the starting point and the ending point of a target cloud and give an emissivity in the same manner with MM-1 procedure as described above. Information on the location of selected points and assigned emissivities is accumulated in a disk pack for successive processing. This procedure is prepared for research purpose and is not used in routine operations.

3.2. Automatical tracking

MM-2 target clouds are tracked in man-machine interactive procedure as mentioned above, so the processing described in this section is applied to MM-1 target clouds.

The same cloud pattern of each target

cloud selected in man-machine interactive procedure is searched on another image with 30 minutes interval using cross-correlation technique. On the first picture, digital image data of 32 pixels by 32 lines, 16 by 16, or 8 by 8 centered at a selected point is put into a computer as a template data. On the second picture taken at 30 minutes later or before, image data of 64 by 64 is put into a computer as a search area data. The correlation values of the brightness between the template and the search area are calculated for different lag values and a cross-correlation coefficient matrix is obtained as the result. The correlation matrix is given by:

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

where

$T(i, j)$ Brightness level of template data

$i, j=1, 2, 3, \cdots, N$

$S(i+p, j+q)$ Brightness level of search area data

$i, j=1, 2, 3, \cdots, N$

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

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

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

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

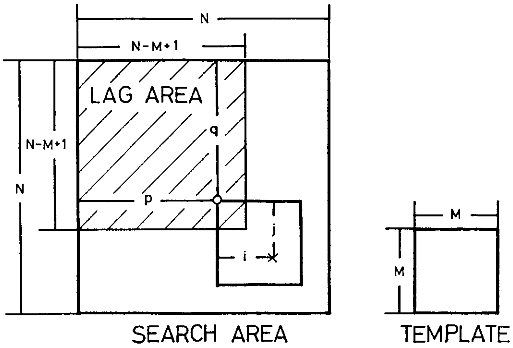


Fig. II-2 Schematic of search area and template area used for calculating cross-correlation matrix.

Schematics of relation between the template area and search area used for calculating cross-correlation matrix is shown in Fig. II-2. Leese et al. (1971) and Smith et al. (1972) applied a cross-correlation technique to derivation of a cloud displacement for the first time.

The cross-correlation coefficient matrix is depicted in three dimensional feature as shown in Fig. II-3. It is called a matching surface and used for quality control on matching results, as described in Section 4.

Double matching method shown in Fig. II-4, is adopted in tracking target clouds in MM-1 procedure. At first, on sampled images each selected target cloud is tracked and a coarse vector of displacement is derived, which is called coarse matching. Next, on original spatial resolution images, a correction vector is derived in similar processing of coarse matching, which is called fine matching. Sum of the coarse vector and the correction vector is a final result of cloud displacement. The sampling rate in the coarse matching is given in the process of initial parameter set.

We usually use three images for MM-1 procedure (Fig. II-5). These images are

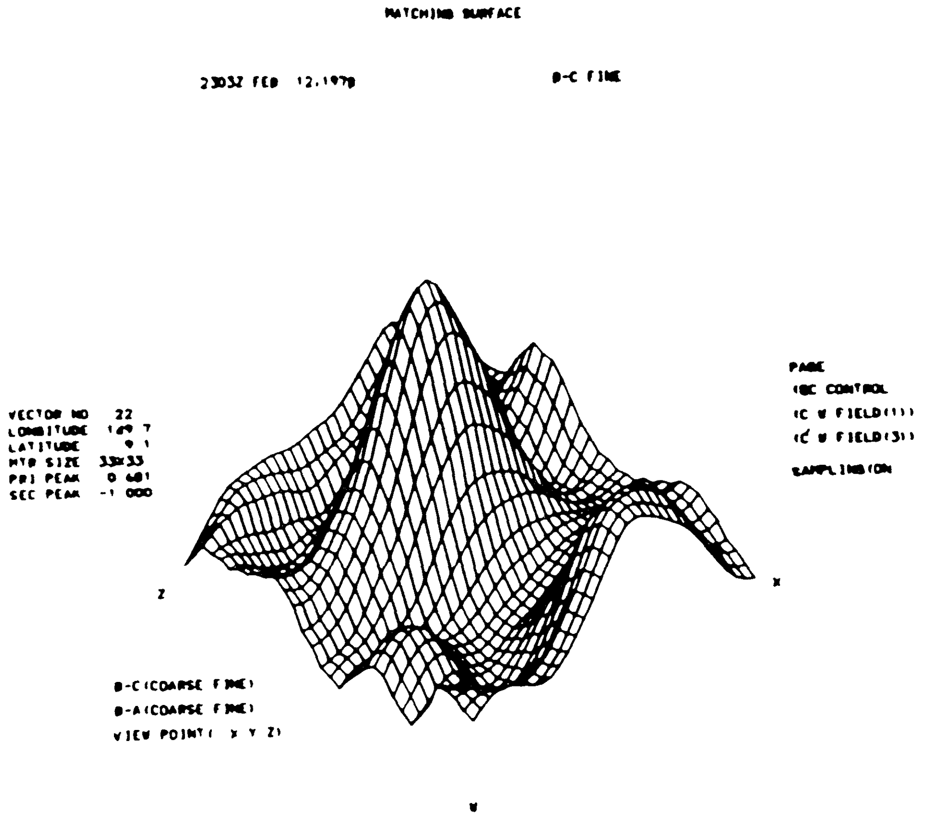


Fig. II-3 Matching surface displayed on the screen of a graphic display.

A-, *B*- and *C*-image with time intervals of 30 minutes. We select target clouds on *B*-image and double matching method is applied to deriving target cloud displacement between *B*- and *C*-image. The inverse vector from *B*-image to *C*-image is defined as a coarse vector between *B*-image and *A*-image. Only fine matching is processed between *B*-image and *A*-image. Consequently we get two consecutive vectors, V_{AB} and V_{BC}, corresponding to every selected target cloud on *B*-image.

Matching scheme mentioned above are used for routine operation. The two image operation mode in Fig. II-5 is provided for the case lacking one of these images.

The image data used for matching process are composed of picture elements at discrete position, which causes truncation error to the cloud drift winds. In order to eliminate the truncation error, interpolation of matching position where the maximum correlation value occurs is applied to the result of fine matching. The interpolation substantially increase the spatial resolution and is effective to be applied to the result from infrared image because of worse resolution than this of visible image. The procedure in CWES system, to increase the resolution of the image match surface, is to fit a bi-directional quadratic in the neighborhood of the best match coefficient, which was de-

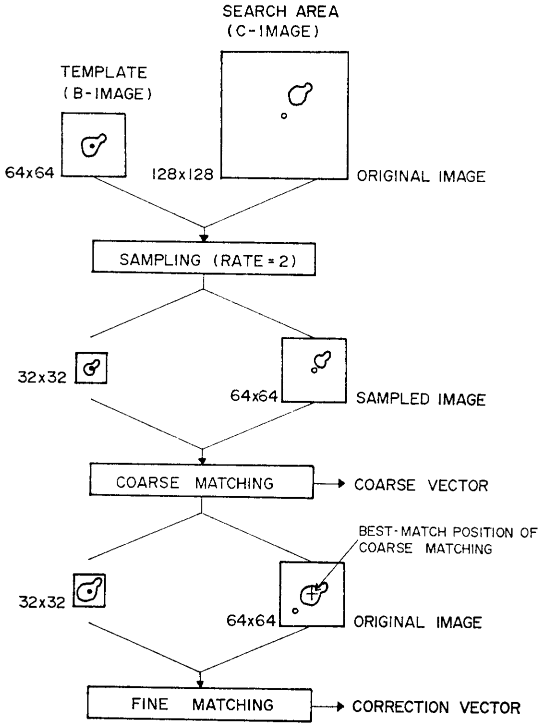


Fig. II-4 Schematic of double matching in CWES system. Sampling rate of coarse matching is given in the process of initial parameter set.

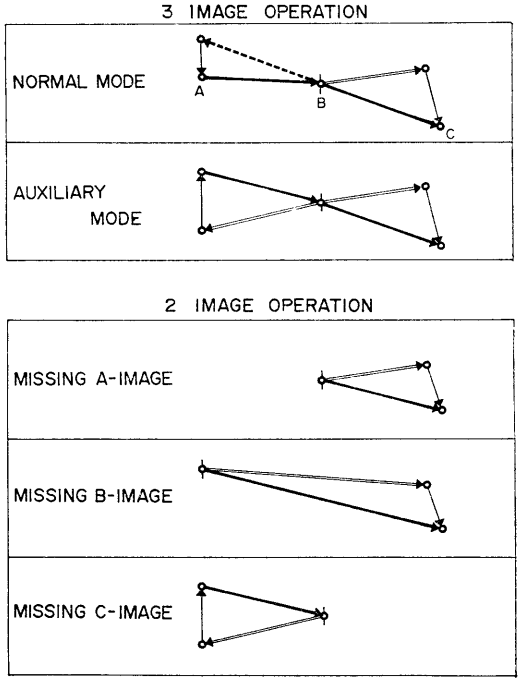


Fig. II-5 Matching scheme due to the number of ingested images. Usually three images (*A*, *B* and *C*) with 30-minute intervals are used for matching process. The mark "ɸ" depicts an image used for target cloud selection. Vectors depicted by doublet are coarse ones, thin line vectors are correction ones deriving through fine matching procedures, and heavy line vectors are the resultant vectors. The broken line vector in normal mode is an inverse vector of the resultant vector between *B*- and *C*-image, and is replaced with a coarse vector between *A*- and *B*-image.

veloped at SSEC, the University of Wisconsin (see Smith et al., 1973).

3.3. Wind derivation and height assignment

The resultant vectors on the image co-ordinate system are transformed into wind vectors on the earth co-ordinate system on the basis of attitude and orbital predicted data. The vectors between *B*- and *C*-image are regarded as final winds, and vectors between *A*- and *B*-image are used for quality control of wind vectors.

Three cloud top heights (CTHs) are derived from three infrared images for each wind data. The CTH derived from the latest image is assigned to a current vector. A black body temperature, T_{BB}, is extracted from a small infrared image array centered at a selected point in target cloud selection or at a matching point in matching procedure. T_{BB} is modified into a temperature of cloud top, T_C, considering atmospheric attenuation. Using climatological data of vertical temperature profiles prepared on grid points with five degree interval in latitude and longitude, T_C is transformed into CTH both in pressure level and in geo-potential height.

3.4. Wind derivation using film-loop

A 35 mm motion picture film, produced from four consecutive images with 30-minute intervals, is used for deriving winds. These pictures are called *Z*-, *A*-, *B*- and *C*-image. Latter three images are the same with those used in man-machine interactive procedures.

The film-loop is projected on digitizer board which is two dimensional co-ordinate measuring system coupling with card punch device. Analyst selects and tracks bench marks printed in each frame of the film-loop, and the locations of the tracking points on the digitizer board are punched on data cards.

Locations of tracking points of target clouds are also punched in the same way as above. After finishing these works, a control card and several identification cards (ID cards) are interposed into that card deck. The control card specifies type of image used for target cloud tracking and the ID cards specify the mean of cloud top height assignment. Complete card deck is input data of film-loop wind derivation and cloud top height assignment program. In this program the digitizer co-ordinates are transformed into image co-ordinates referring to the nearest three bench mark locations. And then final wind vectors are extracted in the same way with MM-1 procedure.

4. Quality control in CWES system.

Quality control of CWES system is divided into two stages as shown in Table II-2. The first stage is the automatic assessment of matching surfaces, wind velocities, cloud top heights and

Table II-2 Quality control of CWES.

Automatical assessment
1) The features of matching surface
2) Picture-to-picture variation of cloud top heights
3) Wind acceleration
4) Checking on missing lines of the images used for matching process
5) Checking on missing lines of IR images used for cloud top height assignment

Manual quality control
—Using graphic display
1) Checking on horizontal consistency
2) Comparison with rawin sonde winds
3) Checking on the features of matching surface
—Using TV-display
1) Checking on reasonability of automatical tracking
—Using film-loop
1) Checking on identity of each result vector with film-loop displacement (Projection Method)

missing line (line drop) check. The second stage is the man machine interactive quality control of the resultant winds, which is performed by using graphic display and TV-display, and by means of film-loop projection.

4.1. Automatic assessment

The resultant vectors are assessed automatically by checking on threshold values given by the initial parameter set program. The threshold values are pre-determined by another investigation. Each resultant vector screened out automatically on the basis of the threshold values, and unreliable vectors are excluded in the final report. Contents of the automatic assessment are as follows (see Table II-2);

1) *The features of matching surface.*

The parameterization of a matching surface is shown in Fig. II-6. A sample of a matching surface displayed on a graphic display is shown in Fig. II-3. The threshold values are determined by another investigation and are improved empirically. The relationship between R (the difference of dominant and second peak value) and D (the distance of dominant and second peak position) is assessed automatically. In case that R is smaller than threshold value and D is greater than threshold value, the vector is sent to manual check procedure as a failure of the automatic assessment. The relationship of them is shown in Table II-3.

2) *Picture to picture variation of cloud top heights.*

Two or three cloud top heights are extracted from a same target cloud in MM-1 and MM-2 procedure, and their variations are checked automatically. Unreliable vectors derived from convective

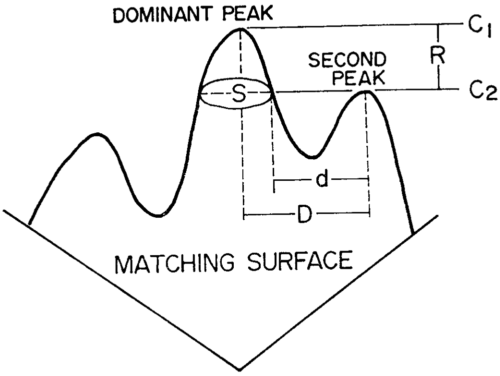


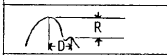
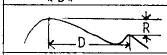
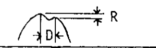
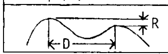
Fig. II-6 Parameterization of a matching surface with multiple peaks.

Parameters:

1. Peak value (Maximum correlation coefficient) C_1
2. Sharpness around dominant peak $P=R^2/S$
3. The difference between values of dominant peak and second peak $R=C_1-C_2$
4. The distance between lag-positions of dominant peak and second peak D
5. Maximum lag-value

"S" means area dominated by stronger peak with respect to second peak. The distance, d, is used for searching second peak.

Table II-3 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)**

* Quality flag ; '1' or '0' is assigned to the flag in case that the parameter value is smaller or greater than threshold value respectively

** At the same time cross-correlation matrices are preserved on DP for inspecting them in the process of interactive quality check.

clouds developing or decaying rapidly and mismatching vectors are rejected by this means.

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 wind. This procedure is very effective to reject mismatched vectors.

4) *Missing line check on the images used for matching process.*

When template image data or search area image data used for matching process include missing line(s) less than two/five lines in infrared/visible image, the matching result may be slightly degraded. In case that more than or equal to two/five lines in infrared/visible template or search area are missing, current vector is immediately rejected.

5) *Missing line check on infrared image used for CTH assignment.*

This is the missing line check on infrared image used for cloud top height (CTH) extraction. In case that missing lines are more than two, cloud top height extraction is not made from the image.

The functions of items 1 and 4 are done in the process of matching, and the items

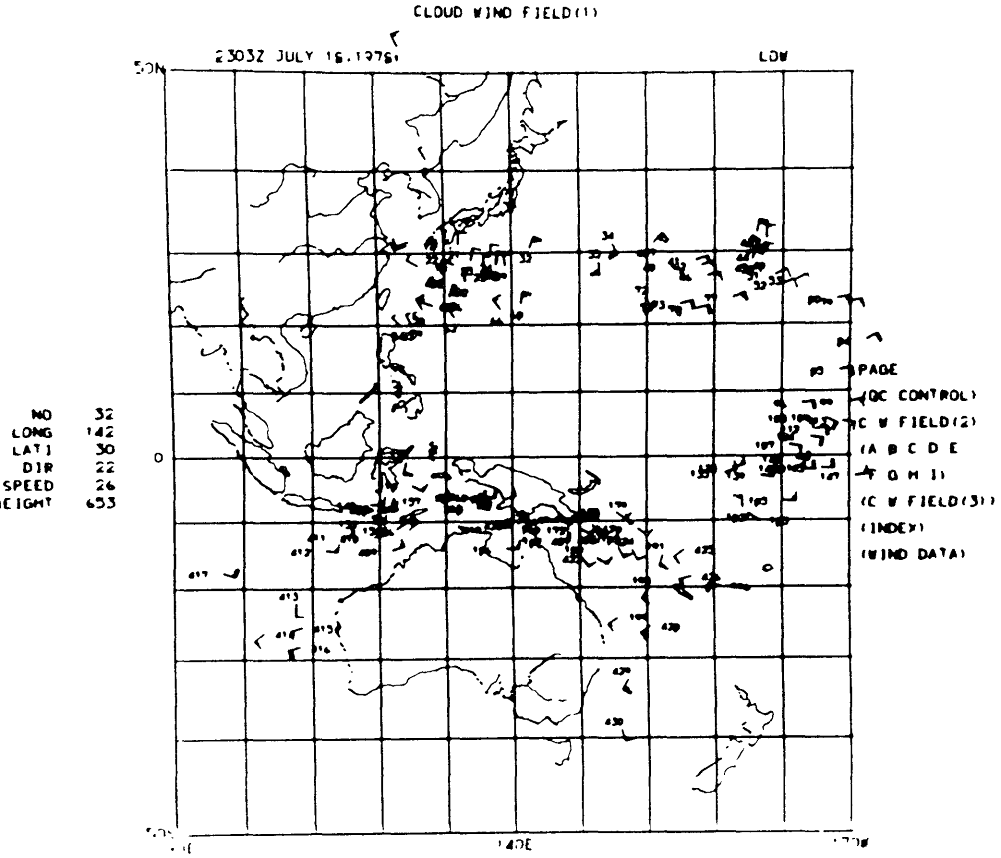


Fig. II-7 Low cloud drift winds derived from CWES system at 00Z, July 19, 1978, which are depicted on the screen of a graphic display for horizontal consistency check.

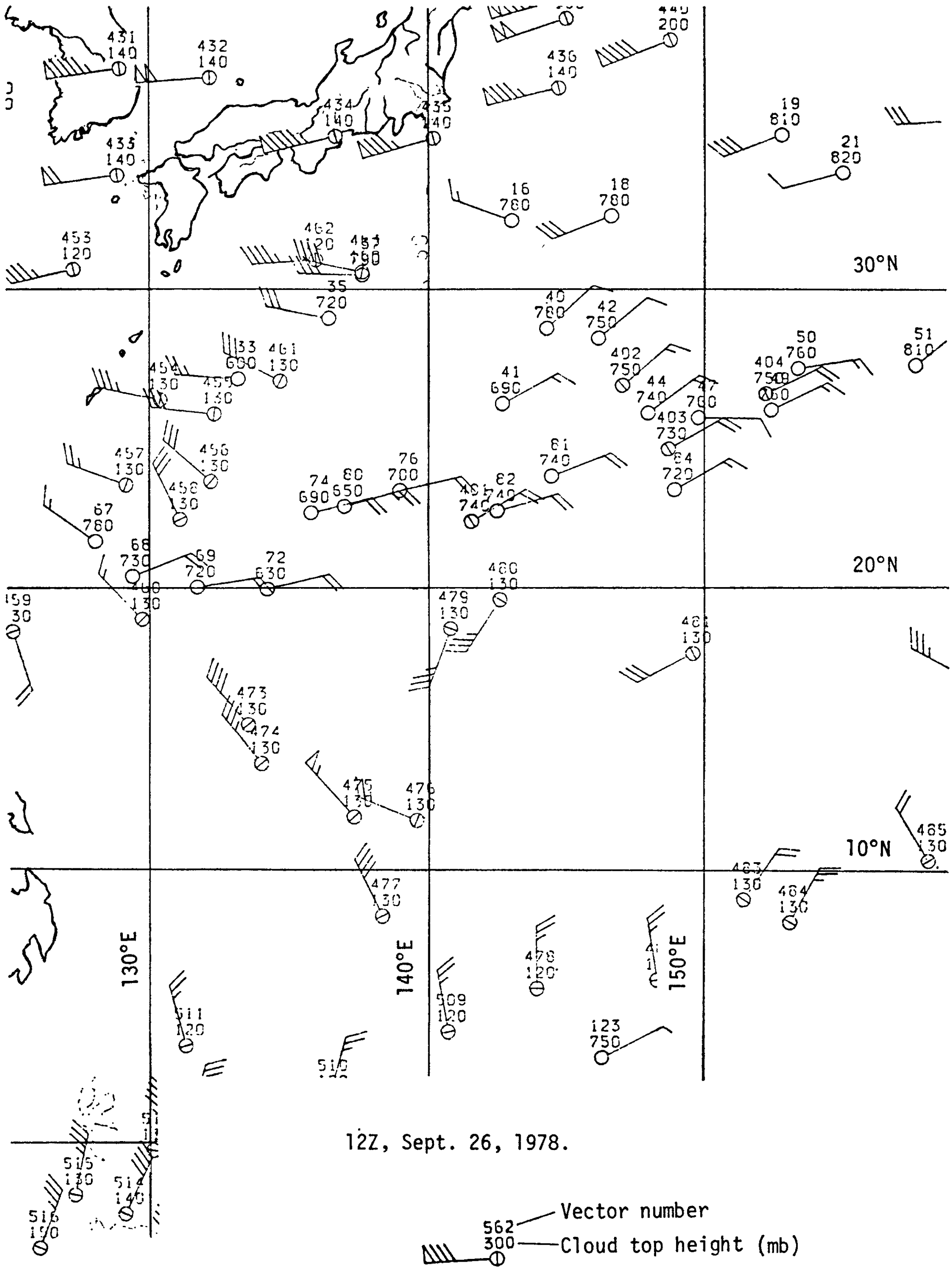


Fig. II-8 A sample of mapped wind data derived from CWES system at 12Z, Sept. 26, 1978.

2, 3 and 5, in the process of wind derivation and cloud top height assignment.

4.2. Man-machine interactive quality control

Manual quality control is performed in interactive procedures.

Using a graphic display

1) *Checking on horizontal consistency.*

Horizontal consistency of resultant vectors are checked by depicting all resultant wind vectors on a graphic display. Wind vectors depicted on a graphic display are shown in Fig. II-7.

2) *Comparison with rawinsonde winds.*

Resultant vectors are compared with rawinsonde winds ingested in realtime on a graphic display. Two kinds of comparisons are performed. One is a comparison of a resultant vector with nearby rawinsonde wind having the same altitude with cloud top height assigned to the resultant wind. Another is a comparison of a resultant vector with the same rawinsonde wind to find a level of best fit, LBF. With these comparison procedures analyst checks the vector in question.

3) *Checking on the features of matching surface.*

Matching surface is checked on a graphic display by inspecting three dimensional feature of surface. This function is provided for determination of threshold values of parameters characterizing a matching surface. Usually it is not used in routine operations.

Using TV-display

1) *Checking on reasonability of automatic traking.*

Resultant vectors and three consecutive pictures can be superimposed on TV-display. It is easy for analyst to check on reasonability of automatic tracking.

Using film-loop

1) *Projection Method.*

The resultant vectors are plotted on a map of whole disk projection as viewed of GMS satellite. Film-loop used for target cloud tracking is projected on the map, and analyst checks on identity of each resultant vector with displacement of cloud. We call this procedure Projection Method or PM method.

In these procedures except matching surface check and PM method, analyst can reject unreliable vectors from an alpha-numeric key board of either TV-display or graphic display console.

5. Delivery and archiving

The product vectors considered reliable are reformatted by a computer into a WMO code from for teletype transmission to world wide users. The transmission of these data is done within four hours from VISSR observation. These vectors are stored in a magnetic tape to be archived, listed by a line-printer and plotted on the map with polar-stereo and Mercator's projection. These wind data are included in the "Monthly Report" issued by Meteorological Satellite Center every month. Resultant vectors derived in routine operation at 12 Z, Sept. 26, 1978 are shown in Fig. II-8.

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